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C. J. WILLARD, *Editor*, Department of Agronomy, The Ohio State University, 1827 Neil Ave., Columbus 10, Ohio

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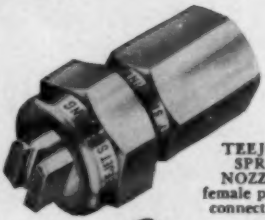

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JOURNAL OF THE WEED SOCIETY OF AMERICA

VOLUME 9 JANUARY 1961 NUMBER 1

Uptake and Distribution of Simazine by Oat and Cotton Seedlings[1]

T. J. SHEETS[2]

FOR most effective weed control 2–chloro–4,6–bis(ethylamino) –*s*–triazine (simazine) must be applied to the soil. As a foliar spray it is much less effective. Simazine penetrates into leaves of some plants[3], but apparently the cuticle is a barrier to foliar absorption of this herbicide (5). It is absorbed rapidly by roots and is transported upward to the aerial plant parts.

Corn is exceptionally tolerant to simazine, but many annual weeds are highly susceptible (1). Oat plants are extremely sensitive, but cotton exhibits some tolerance (5,15). Roth (14) suggested that the resistance of corn was due to a thermolabile system in corn tissues which metabolized simazine to a biologically inactive product.

The experiments described herein were undertaken (a) to study the gross uptake and distribution of simazine in oat (very susceptible) and cotton (intermediately susceptible) seedlings, (b) to evaluate the relation between the concentration of simazine in the culture solution and the amount of simazine absorbed and translocated, (c) to determine the influence of temperature and relative humidity on the absorption and translocation of simazine in oat and cotton plants, (d) to relate the amount of simazine in the leaves to total transpiration, and (e) to estimate tentatively the metabolic change of simazine in plant tissues.

METHODS AND MATERIALS

Culture of plants. A stock solution which contained 2.0 ppmw of C^{14} ring-labeled simazine (specific activity, 0.83 mC per mM)[4] in

[1]Received for publication Dec. 17, 1959. Cooperative investigations of the Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture and the California Agricultural Experiment Station.

[2]Plant physiologist, Crops Research Division, Agricultural Research Service, U. S Department of Agriculture, Stoneville, Mississippi; formerly Agronomist, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, University of California, Davis, California.

[3]Crafts, A. S. and Yamaguchi, S., Unpublished data, Department of Botany, University of California, Davis, California.

[4]C^{14} ring-labeled 2–chloro–4, 6–bis (ethylamino)–*s*–triazine was supplied by Geigy Chemical Corporation, Yonkers, New York.

distilled water was prepared and stored in the freezing compartment of a refrigerator. Twelve hours prior to use, the stock was removed from the refrigerator. The unused portion was returned to the freezing compartment for storage. Ten, 12.2, and 20 ml of stock were added to 390, 388, and 380 ml respectively of nutrient solution 1 described by Hoagland and Arnon (9) to form cultures containing 0.05, 0.061, and 0.10 ppmw of simazine (0.082, 0.100, and 0.165 μC).

Seeds of oat (*Avena sativa* L., var. Kanota) and cotton (*Gossypium hirsutum* L., var. Acala 4–42) were germinated in autoclaved sand. When the oat seedlings were 7 to 8 cm high, they were transferred to 1-pint, wide-mouth, mason jars containing 400 ml of nutrient solution. The oat seedlings were transferred to the treatment solutions when the first leaf of the oat plants was mature and the second about half mature. Three oat plants were used per jar in the time-series experiments. In all other experiments there were four oat plants per jar. The cotton seedlings were transferred to the 400 ml of nutrient solution in 1-pint, narrow-mouth mason jars when the cotyledons were approximately 3 cm in diameter. At the time the cotton plants were transferred to the treatment solutions, the cotyledons were fully expanded and the first leaf above the cotyledons was 1 to 2 cm in diameter. There were two cotton plants per jar. All plants were grown in the greenhouse prior to transfer to solutions containing simazine.

In several experiments the test plants were placed in an environmental control chamber immediately after treatment. Temperature was thermostatically regulated. A saturated solution of calcium chloride maintained the relative humidity at 33 ± 3 per cent. A solution of sodium chloride maintained the relative humidity at 66 ± 5 per cent. A bank of fluorescent tubes and incandescent lamps provided a light intensity of 1100 to 1300 foot-candles at the level of the plant leaves. The incandescent lamps supplied about 10 per cent of the visible light.

Assay methods. The radioautographic method was used to determine the general distribution pattern of C^{14} in plants after exposure of the roots to solutions containing ring-labeled simazine. The plants were removed from the treatment solutions, and the roots were blotted with soft tissue. The intact plants were killed with crushed, solid carbon dioxide, dried in a frozen condition, and radioautographed (16).

When counts were the only data to be collected, the plant tissues were dried in the oven. The oat plants were divided into roots and tops; and the cotton plants were divided into leaves, stems, and roots. The roots of both species were blotted with soft tissue, and all plant parts were oven-dried at 60°C.

The dry plant tissue (freeze-dried or oven-dried) was ground in a Wiley mill with a 40-mesh screen. The ground sample was packed uniformly in a nickel plated planchet with an inside diameter of 2.42 cm. Dry weights were determined before and after grinding.

The samples were counted with a thin-window Geiger-Muller tube and Tracerlab "1000" scaler. Sufficient counts were made on most samples to maintain precision within about 6 per cent error. Self-absorption curves were established for oat leaf and root tissue (7). The two curves were almost superimposable, and differences were probably attributable to experimental error. Counts of all unknown samples (oat and cotton tissues) were corrected for self-absorption.

A procedure for determining the amount of simazine residue in tissues of the corn plant was developed by Gigger[5]. The method involved Soxhlet extraction of simazine with chloroform, hydrolysis of the 2–chloro form to 2–hydroxy–4,6–bis(ethylamino)–*s*–triazine, transfer of the hydrolytic product to water, and determination of the amount present spectrophotometrically. Since the plant tissues which were used in these experiments contained C^{14}, the extracts and fractions were assayed by counting. Aqueous extracts and washes were treated with 5 mg of activated charcoal (Norite), and the mixtures were agitated vigorously several times during a 15-minute period. By suction filtration the charcoal was separated and collected on filter paper in a thin, uniform layer for counting. Five mg of charcoal were found by experiment to absorb approximately 28.5 per cent of the radiation. Counts of charcoal residues, sodium-sulfate residues, and plant-meal residues from the extraction experiments were corrected for absorption of radiation by the residues.

General uptake and distribution of simazine in oat and cotton seedlings. Seedling oat and cotton plants were placed in solutions containing 0.10 ppmw of simazine, and the cultures were moved immediately to the growth chamber. The chamber was adjusted for 12-hour days and 12-hour nights. The day and night temperatures were 24 ± 2 and 19 ± 2°C respectively. The relative humidity was not controlled. After 72 hours the plants were removed from the solutions and radioautographed.

Effects of time of exposure and concentration of simazine. Twenty cultures of seedling oats were divided into four groups of five jars each. The solution culture for two of the groups contained 0.061 ppmw of simazine. The remaining groups were untreated. One treated group and one untreated group of plants were aerated by passing air through capillaries with the open ends submerged in the solutions. The jars were placed at random on the greenhouse bench. One culture from each group was harvested 12, 24, 48, 96, and 168 hours after the treatments were initiated. Representative plants of the aerated-simazine series were radioautographed and subsequently the tops and roots of all plants from the treated cultures were ground and quantitatively assayed for C^{14} by counting.

Roots of oat plants were subjected to concentrations of 0.05 and 0.10 ppmw of simazine for 3, 6, 12, 24, and 48 hours in the greenhouse. The radioautographic method of assay was employed.

[5]Gigger, R. P. Analysis of simazine residues. Analytical Laboratory, Geigy Chemical Corporation, Basel, Switzerland, unpublished.

Oat and cotton plants were transferred to solutions containing 0.05 and 0.10 ppmw of simazine. The cultures were placed in the growth chamber immediately. The temperature was 27 ± 1°C, the relative humidity 33 ± 3 per cent, and light continuous during the experiment. One half of the cultures for each species was harvested after 12 hours; the remainder was harvested after 24 hours. The experiment contained four replications. At the prescribed time, the plants were removed from the solutions and processed for oven-drying. The total water loss for each culture was determined by difference between the weight of the solution before and after exposure with corrections for evaporational loss. Although corrections for changes in plant weights were not made, the corrected water loss should closely approximate transpirational loss. The amounts of C^{14} in the leaf and root tissues were determined and studied with respect to the concentration of simazine in solution and total water loss.

Effects of temperature and relative humidity. Oat and cotton plants were transferred to solutions containing 0.10 ppmw of simazine, and the cultures were placed in the growth chamber which had been adjusted previously and allowed to equilibrate. Three experimental conditions involving temperature and relative humidity variables were employed (Table 2). Four cultures of oat and four of cotton seedlings were used for each environmental condition, and each condition was repeated once. Thus, there were eight cultures of each plant per environmental condition. The plants were exposed to the experimental conditions for 24 hours. Light was continuous during this time. At the end of the exposure period, the plant parts were oven-dried. The total water loss during the treatment period was determined for all cultures.

Solvent extraction of plant tissues. Root and leaf meals (420 and 385 mg respectively) from treated oat plants which were grown at 37°C and 66 per cent relative humidity were selected. Dry-meal samples (400 mg) from control plants were treated with labeled simazine (0.0275 μC) 14 hours prior to the initial extraction. After the plant-meal samples were ground in a mortar with 2.52 g of anhydrous sodium sulfate, they were extracted with 170 ml of chloroform in a Soxhlet apparatus for 18 hours[5]. The plant-meal residues were saved for additional extraction.

The chloroform extracts were transferred to 300-ml separatory funnels, and 25 ml of 2 per cent sodium hydroxide were added to each. The mixtures were shaken for 1 minute and allowed to separate for at least 45 minutes. The basic washes were removed, and the chloroform extracts were washed three times with 25 ml of 0.5 N sulfuric acid. Each acid wash separated at least 20 minutes. It was necessary to centrifuge the aqueous washes to break the emulsion. The acid washes were combined. The aqueous washes were saved for assay.

The chloroform extracts were transferred to 250-ml distilling flasks, and 1 ml of 50 per cent sulfuric acid was added to each. The

mixtures were refluxed for 1 hour. Simazine is hydrolyzed to hydroxy simazine by this treatment[5]. After the mixtures cooled to room temperature, 9 ml of distilled water were added to each. The contents were transferred to 300-ml separatory funnels and were shaken vigorously for 1 minute. After separation, the water layer in each separatory funnel was removed and the chloroform was extracted once more with 10 ml water. The water extracts were combined and centrifuged to remove the emulsion. An aliquot of each chloroform remainder was transferred to a planchet 1 ml at a time, the chloroform was evaporated, and the residue was counted.

The plant meal-sodium sulfate residues which remained after extraction with chloroform were transferred to 250-ml beakers, and each was extracted with 50 ml of distilled water. The mixtures were filtered with suction, and the residues were extracted twice more with 25-ml portions of distilled water. The three extracts from each residue were combined. The plant residues were plated and counted.

A 25-ml aliquot of each of the aqueous-sodium sulfate extracts was dialyzed in distilled water for 24 hours. The solutions in the dialysis membranes were transferred to 125-ml Erlenmeyer flasks. Each solution received two successive charcoal treatments; each charcoal treatment was followed by suction filtration. The filtrates were discarded after the second filtration.

The aqueous washes, the aqueous extracts of the chloroform after acid hydrolysis, and 25-ml aliquots of the aqueous extracts of the plant tissue were treated with activated charcoal and filtered. The charcoal treatments and filtrations were repeated three times. The charcoal residues were assayed for C^{14} by counting. After the final filtration the effluent liquids from the aqueous-sodium sulfate extracts were evaporated to dryness, and the residues were transferred to a planchet for counting. The other filtrates were discarded.

Dry-meal samples of oat leaf (535 mg), oat root (451 mg), cotton leaf (962 mg), and cotton root (369 mg) were selected from plants which were grown at 37°C and 66 per cent relative humidity, and the distribution of C^{14} in extracts and fractions of the tissues was compared. Changes in the analytical scheme of the previous experiment follow: The plant meals were not ground with anhydrous sodium sulfate. Aliquots of the aqueous extracts were not dialyzed. An aliquot of the aqueous extract was plated for counting prior to charcoal treatment.

RESULTS AND DISCUSSION

In the presentation and discussion of the results of these experiments, the C^{14} in the plant tissue was, for simplicity, often referred to as simazine. However, in plants harvested after a 24-hour exposure to the labeled herbicide, much of the observed C^{14} was not simazine. Since the oat tops were largely leaf tissue, oat tops and oat leaves were used interchangeably in this section.

General distribution of simazine in oat and cotton seedlings. The

uptake and distribution of simazine by oat and cotton seedlings are pictorially shown in Figure 1. The seedlings were cultured for 72 hours in full-strength Hoagland's solution containing 0.10 ppmw of simazine. Accumulation[6] of simazine occurred in the oat leaves. Areas of accumulation were not as apparent in cotton leaves as in oat leaves; however, dense spots on the radioautograph appeared to coincide with lycigenous glands on the cotton stem. Davis et al. (5) reported similar results. The presence of C^{14} in the oldest leaves and its scarcity in the youngest leaves of the cotton plant suggest that simazine was carried upward in the transpiration stream and that phloem movement of molecular simazine out of the mature leaves into the growing point probably did not occur.

Figure 1. Uptake of simazine and distribution of C^{14} by roots of cotton and oat seedlings. The plants and the radioautograph of the plants are shown in A and B respectively. The oat plant and the cotton plant on the left were grown for 72 hours in solutions containing 0.10 ppmw of simazine. The middle plant (cotton) was not treated.

Effects of time of exposure and concentration of simazine. Simazine was distributed throughout seedling-oat plants after only 3 hours of exposure to treated solutions. Accumulation of simazine in the leaf tips of oat plants began within 48 hours after exposure. As the exposure time increased, the leaf area in which accumulation occurred increased in size. Accumulation began in the same area of the oat leaf as the first injury symptoms, and the subsequent accumulation pattern within the leaf was identical with the basipetal development of injury symptoms. The leaf tips of plants which were exposed for 168 hours were necrotic at harvest. Accumulation occurred in the older part of the leaf where transpiration presumably occurred most rapidly.

The dry weight of tops of simazine-treated plants appeared to be less than that of corresponding control-plant parts for exposure periods greater than 24 hours. A reduction in the dry weight of roots of treated plants, presumably a secondary effect of photo-

[6]As used here accumulation refers to the deposition of simazine or C^{14}-labeled metabolic products in plant organs or parts of organs in excess of the level for the plant as a whole.

synthesis inhibition in the leaves, was not apparent except for the 168-hour exposure.

In Figure 2 the specific activity, which is counts per minute (cpm) per mg of dry tissue, is plotted against the exposure time in hours. The amount of simazine in the tops increased as the time of exposure increased. The level in roots increased very little, if at all, after 48 hours of exposure. The specific activity in the tops was not affected by aeration of the solutions in which the plants grew. The difference between aerated and unaerated roots at the 168-hour exposure time may render such a general conclusion questionable for the root tissues.

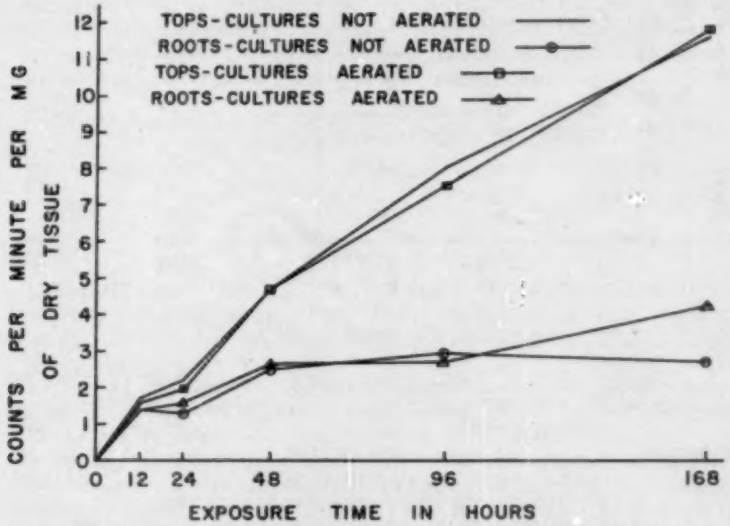

Figure 2. Effect of time of exposure and aeration on the absorption of simazine and distribution of C^{14} in seedling oats.

The uptake of simazine and accumulation of C^{14} in oat and cotton plants were studied with respect to the concentration of simazine in solution culture, length of the exposure time, and total water loss. For cotton plants a direct relation was found between the specific activity of dry tissue and the concentration of simazine in the solution (Figure 3D). The relationship was non-linear for oat plants. The concentration of simazine in tissues of oat plants which were cultured in solutions of 0.10 ppmw of simazine was less than twice the concentration in the tissues of plants cultured in solutions of 0.05 ppmw of simazine. The curves for leaf, root, and stem tissues (Figure 3A, 3B, 3C) were very similar to those for the whole plants.

The relation betweeen total uptake of simazine and the amount of water transpired is shown in Table 1. The ratio, cpm in the

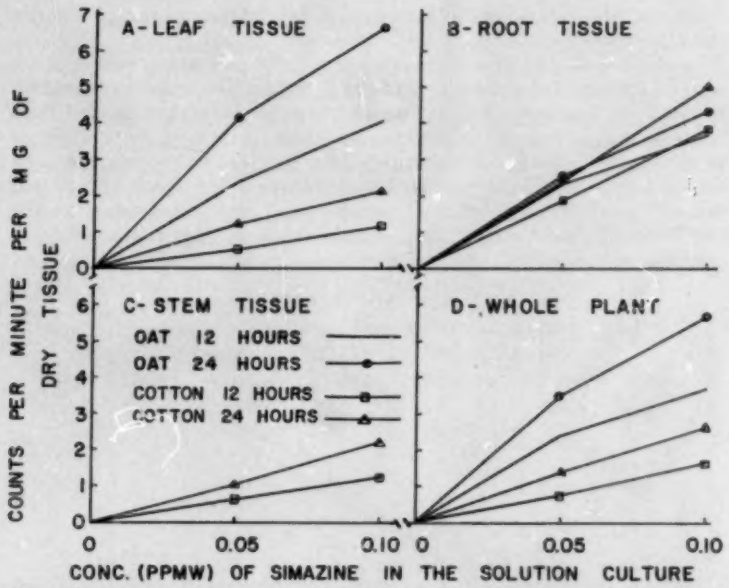

Figure 3. Relation between the specific activity in oat and cotton plants and the concentration of simazine in the solution culture.

plant tissue per ml of water transpired, appeared to be a linear function of the concentration of simazine in the culture solution. In only one instance did the cpm in plant tissue (total uptake) per ml of water transpired equal the concentration in the culture solution. It appears therefore that simazine uptake was preferentially retarded relative to water absorption or that simazine was metabolized in the plants and that part of the C^{14} was lost as carbon dioxide (8, 12).

Table 1. Relation between simazine absorption and transpiration of oat and cotton seedlings.

Plant	Conc. of simazine in solution		Exposure time in hours	Counts per minute in plant tissue	Ml water transpired during exposure	Counts per minute in plant tissue per ml water transpired
	ppmw	Counts per minute per ml				
Oat	0.05	25	12	505[a]	20[a]	26
	0.05	25	24	841	42	20
	0.10	49	12	836	20	42
	0.10	49	24	1234	30	41
Cotton	0.05	25	12	306	15	20
	0.05	25	24	601	34	18
	0.10	49	12	632	16	40
	0.10	49	24	1112	30	38

[a]Each value is an average of four replications.

Oat leaves contained higher concentrations of simazine or C^{14}–labeled metabolites than oat roots, whereas in cotton plants the roots contained higher concentrations than the leaves (Figure 3A, 3B). The results suggest that roots of cotton plants may fix, metabolically absorb, or metabolize a larger proportion of the simazine than the roots of oat plants.

Effects of temperature and relative humidity. The three environmental conditions were established at different times, and each condition was repeated once. Since few significant differences were found between replications within environmental conditions, the observations from the two replications were assumed to be from the same population. Therefore means and standard errors of the means based on eight individual observations (four from each replication) were computed, and 5 per cent probability limits were calculated for each mean (Table 2).

Table 2. Counts per minute per mg of dry meal from oat and cotton plants grown under three environmental conditions.

Temperature °C	Relative humidity Pct.	Oat leaf	Oat root	Cotton leaf	Cotton root	Cotton stem
26±1	33±3	4.6±0.4[a]	3.8±0.4	1.6±0.2	3.7±0.3	1.2
37±2	33±3	10.5±1.0	4.6±0.6	3.5±0.4	4.4±0.3	1.3
37±2	66±5	8.2±0.7	5.2±0.4	2.8±0.2	6.0±1.5	1.6

[a]Mean and the 5 per cent probability limit. Each probability limit is the product of the standard error of the mean and the value of *t* at the 5 per cent level. Cotton stem data were not analyzed statistically.

Temperature markedly influenced the accumulation of simazine in the leaves of oat and cotton plants. With the relative humidity constant, the leaf tissue of plants grown in the 37°C environment contained more than twice the concentration of simazine in plants grown in the 26°C environment. With relative humidity constant, the concentration of simazine in the roots of cotton plants grown at 37°C was greater than the simazine concentration in cotton roots grown at 26°C. The trend was similar for oat roots at the two temperatures. Total uptake of simazine from solution was much greater at 37 than at 26°C.

With temperature constant at 37°C the concentration of simazine in the leaves of both plants grown under the 66 per cent relative humidity environment was lower than the concentration of simazine in the leaves of plants grown under the 33 per cent relative humidity environment.

A trend toward greater quantities of simazine in oat leaves than in cotton leaves per unit of water transpired was observed. There was also a trend toward greater quantities of simazine per unit of water loss in the leaves of plants grown in the 37°C environment than by plants grown in the 26°C environment.

In an experiment with excised bean plants Minshall (11) observed that 3–(*p*–chlorophenyl)–1,1–dimethylurea (monuron) accumulated

in leaves exposed to light. Lethal concentrations were present within a few days. The herbicide did not accumulate in shaded leaves. In intact plants symptoms of monuron injury developed more slowly than in excised plants. Minshall concluded that monuron was absorbed by bean roots and was translocated to the leaves in the transpiration stream. The concentration of simazine or C^{14}–labeled metabolites in the leaves of oat plants was approximately three times the concentration in cotton plants when the two species were treated similarly (Table 2). Oat plants lost two to three times as much water per g of dry leaf as cotton plants. Therefore differences in the rates of accumulation of herbicide in the leaves of the two plants were related to, but were not due entirely to, differences in the rates of transpiration.

Hylmö (10) deduced that movement of ions from the soil solution through the roots and stems to the shoots was passive and independent of metabolic absorption. Brouwer (2), on the other hand, reported that water absorption increased more with increased transpiration than anion absorption. In the experiment reported here environmental conditions conducive to rapid transpiration were also conducive to rapid absorption and translocation of simazine. However, the high concentration of simazine in the roots of plants grown at 66 per cent humidity indicates that more simazine was absorbed at 37 than 26°C irrespective of the rate of transpiration. Therefore, the high concentration of simazine in the leaves of plants grown at 37°C cannot be attributed solely to increased transpiration. Rapid translocation doubtlessly was attributable to rapid transpiration. Whether absorption was directly influenced by transpiration cannot be ascertained from these results.

Solvent extraction of plant tissues. The distribution and recovery of C^{14} in extracts and fractions of leaf and root tissues of oat plants are shown in Table 3. Small amounts of C^{14} were present

Table 3. Per cent counts per minute in extracts and fractions of leaf and root tissues of oat plants based on the total counts per minute in the tissue before extraction.

Extract or fraction	Plant meal treated		Growing plant treated	
	Leaf[a]	Root	Leaf	Root
Sodium hydroxide wash of chloroform extract	3	3	3	9
Sulfuric acid wash of chloroform extract	6	3	4	1
Aqueous extract after acid hydrolysis	64	62	37	4
Chloroform remainder after aqueous extraction	1	1	Trace	0
Total chloroform-soluble C^{14}	74	71	44	14
Aqueous sodium sulfate extract, adsorbed on charcoal	2	4	9	15
Aqueous sodium sulfate extract, not adsorbed on charcoal	5	4	23	Trace
Nondialyzable water-soluble fraction	(0)	(0)	(1)	(2)
Total aqueous sodium sulfate extract	7	8	32	15
Plant-meal residue	1	2	9	60
Per cent recovery	82	81	85	89

[a]From left to right the four plant-meal samples contained 3282, 3282, 3453, and 1396 counts per minute before extraction.

in most of the extracts, even those from samples of the dry plant meal to which simazine was added 14 hours before extraction. For the count of a particular extract or residue of treated plants to represent significant metabolic change, the value for the treated plants must exceed the corresponding value for samples to which simazine was added to dry plant meal.

The tissues of plants which grew in simazine solutions for 24 hours contained more water-soluble C^{14} which was not chloroform extractable than tissues to which simazine was added 14 hours prior to extraction. If the simazine ring was broken as proposed by Gysin and Knüsli (8), a variety of water-soluble, low-molecular-weight compounds could be formed from the fragments of the simazine molecule. Plant metabolites presumably present in the sodium sulfate extract included simple sugars, amino acids, water-soluble proteins, and certain organic acids. The large fraction of C^{14}–labeled, water-soluble compounds strongly suggests that the *s*–triazine ring was broken.

Between 1 and 2 percent of the C^{14} was present in the aqueous-sodium sulfate extract as a non-dialyzable fraction. *s*–Triazines which have two chlorine atoms on the ring are known to react with metabolic intermediates containing amino and sulfhydryl groups (3, 4). Perhaps small amounts of simazine reacted similarly within oat plants. Burchfield and Storrs (4) suggested that cysteine, glutathione, *p*–aminobenzoic acid, secondary amines, and pyridine derivatives might be receptor sites for toxicants such as 2,4–dichloro–6–(*o*–chloroanilino)–*s*–triazine.

A large fraction of C^{14} was present in the root tissue as a chloroform-insoluble, water-insoluble component. The plant-meal residue from root tissue contained about 60 per cent of the total C^{14}. For leaf tissue this fraction was about 9 per cent. These results suggest that simazine was more readily metabolized in the roots than in the leaves of oat plants. It is possible, however, that C^{14}–labeled products were transported to the roots following simazine metabolism in the leaves.

The distribution and recovery data for tissues of oat and cotton plants are presented in Table 4. In root tissues of both oat and cotton plants a large percentage of the C^{14} was present as a chloroform-insoluble, water-insoluble fraction in the plant-meal residue. A smaller but significant portion of the C^{14} was water-extractable. These data suggest that a large percentage of the C^{14} in the roots at harvest 24 hours after treatment was no longer in molecular simazine. The percentage of chloroform-soluble C^{14} was greater in leaf tissue than in root tissue of both plants. Therefore in both plants metabolic change of simazine appeared to occur more rapidly in the roots than in the leaves.

Simazine was rapidly metabolized in expressed saps of corn tissues, but it remained largely unchanged in expressed saps of wheat plants (8, 14). Wheat is more susceptible to simazine than corn. Roth suggested that the resistance of corn was attributable to a thermo-

Table 4. Per cent counts per minute in extracts and fractions of leaf and root tissues of oat and cotton plants based on the total counts per minute in the tissue before extraction.

Extract or fraction	Oat leaf[a]		Cotton leaf		Oat root		Cotton root	
Sodium hydroxide wash of chloroform extract	8		7		4		5	
Sulfuric acid wash of chloroform extract	14		9		8		9	
Aqueous extract after acid hydrolysis	23		12		7		11	
Chloroform remainder after aqueous extraction	1		3		1		1	
Total chloroform-soluble C^{14}		46		31		20		26
Water-soluble C^{14} adsorbed on charcoal	19		26		10		20	
Water-soluble C^{14} not absorbed on charcoal	11		11		1		1	
Total water-soluble C^{14}		30		37		11		21
Plant-meal residue		28		30		77		53
Per cent recovery	104		98		108		100	

[a]From left to right the four plant-meal samples contained 4044, 2588, 2082, and 2318 counts per minute before extraction.

labile system which changed the herbicide to an inactive product. The plants of experiments reported here were cultured in simazine solutions for only 24 hours prior to harvest. Oat plants were extremely sensitive to root applications, yet considerable quantities of simazine were apparently metabolized within 24 hours. Cotton plants were more resistant than oats to root applications of the herbicide. The concentration of simazine or C^{14} metabolic products in cotton leaves was about one third as great as in oat leaves. Simazine was equally inhibitory to the Hill reaction regardless of the source of chloroplasts (6, 13). The concentration of active simazine in the leaf tissue must therefore be the factor which controls susceptibility. In addition to differences in the capacity of plants to inactive simazine, the rate of absorption, the rate of translocation (related to transpiration), and the rate of accumulation of simazine in leaf tissue, which is a product of the rate of translocation and the rate of increase in leaf weight, contribute to differential susceptibility among plant species. These factors must interact to produce various degrees of susceptibility and tolerance to simazine as well as to related herbicides.

SUMMARY

The uptake and distribution of C^{14} ring-labelel 2–chloro–4,6–bis(ethylamino)–*s*–triazine (simazine) were investigated in oat and cotton seedlings. The simazine was added to the culture solution in which the plants grew. The radioautographic method of assay was used to determine the general distribution of C^{14} in the seedlings. In most experiments, the plant tissues and extracts of plant tissues were quantitatively assayed by counting.

Simazine was absorbed by the roots, and the C^{14} was distributed throughout seedling oats within 3 hours. Progressive accumulation of C^{14} from tip to base of the oat leaf was identical with the basipetal development of injury symptoms. Absorption of simazine from solution and the translocation of C^{14} upward were both greater

at 37° than at 26°C. With temperature constant at 37°C, absorption and translocation were greater in plants which were grown in a 33 per cent relative humidity environment than in plants which were grown in a 66 per cent relative humidity environment. The concentration of C^{14} in the leaves of oat plants was approximately three times the concentration in the leaves of cotton plants when the two species were subjected to the same experimental conditions. The amount of C^{14} in the leaves appeared to be dependent on transpiration. Assay of solvent extracts of treated-plant tissues showed that a measurable amount of the absorbed simazine was metabolized during the 24-hour exposure period. The simazine molecule was apparently changed more rapidly in roots than in leaves.

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Chemical Weed Control in Seedling Alfalfa
III. Effect of Some Herbicides on Five Varieties[1]

M. K. McCarty and Paul F. Sand[2]

In the central Great Plains, late summer seedings of alfalfa have often been used in order to avoid the annual weed problem associated with spring seedings. Because moisture conditions are unreliable in the fall, development of techniques to reduce the hazard of annual weed competition in spring seedings offers considerable promise. The authors, in previous reports (4, 5), indicated that materials that give adequate control of annual weedy grasses and broad-leaved weeds are available. These tests were made on plantings of Ranger alfalfa.

Review of Literature

Literature dealing with the use of 2,2–dichloropropionic acid (dalapon) and 4–(2,4–dichlorophenoxybutyric acid) [4–(2,4–DB)] to control weeds in seedling alfalfa has been previously reviewed (4, 5). More recently, Dowler and Willard (1) and Elder (2) have reported the successful use of mixtures of 4–(2,4–DB) and dalapon to control both grassy and broad-leaved weeds in alfalfa and birdsfoot trefoil.

Hull and Wakefield (3) reported that excellent control of annual broadleaved weeds and weedy grasses was obtained with a combination of dalapon at 4 lb/A and 4–(2,4–DB) at 1½ or 3 lb/A with little or no injury to alfalfa or birdsfoot trefoil. Yields of legumes were virtually weed free and root and tiller development compared favorably with that on the hand-weeded check plots. Neither dalapon nor 4–(2,4–DB) was satisfactory when applied alone since both weedy grasses and broad-leaved weeds were present in the experimental area.

Materials and Methods

Five varieties of alfalfa, Buffalo, Grimm, Ladak, Ranger, and Vernal, representing a wide germ plasm base, were used in the study. Seedings were made on the Agronomy Farm of the Nebraska Agricultural Experiment Station on April 16, 1957, and April 18, 1958. The 1957 test was on Sharpsburg silty clay loam and the

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[2]Research Agronomist, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture and Assistant in Agronomy, Nebr. Agricultural Experiment Station (now Agronomist, Plant Pest Control Division, in cooperation with Crops Research Divisions, Agricultural Research Service, U. S. Dept. of Agriculture and the North Carolina Agricultural Experiment Station, Whiteville, North Carolina.)

1958 test was on Waukesha silty clay loam. Both areas had been limed within the last 5 years and 40 lb/A P_2O_5 were applied at seeding time.

A split-plot design with 4 replications was used each year. The main plots were weed control treatments and the sub-plots were varieties. Sub-plot size was 5 by 15 feet.

The dimethylamine salt of 4–(2,4–DB) and dalapon were used each year at the rates indicated in Table 1. In addition to the chemically treated plots, hand-weeded plots were included in 1958. One set of hand-weeded plots had the weedy grasses removed, a second the broadleaved weeds, and the third both weedy grasses and broadleaved weeds.

The herbicide applications were made with a portable plot sprayer in 1957 and with a tractor sprayer in 1958. Materials were applied as aqueous sprays at 20 gpa. Treatment dates were June 4, 1957 and May 23, 1958, about 3 weeks after emergence of the alfalfa, which averaged 3 to 4 inches in height. Green and yellow foxtails, (*Setaria viridis* (L.) Beauv. and *S. lutescens* (Weigel) Hubb., respectively) and barnyard grass (*Echinochloa crusgalli* (L.) Beauv.) were the main weedy grasses, and ranged from 2 to 4 inches in height. A few early green foxtail plants were about 6 inches tall and in the early boot stage. Broadleaved weeds were mainly rough pigweed (*Amaranthus retroflexus*, L.), lambsquarters (*Chenopodium album* L.) and some kochia (*Kochia scoparia* (L.) Schrad.). Hand-weeding was completed within a day or two after the chemical treatments were made.

Treatments were evaluated by making stand counts and obtaining yields of alfalfa and weed components. Stand counts of alfalfa stems, weedy grass plants and broadleaved weeds were made in two 2 × 4 foot quadrats in each plot the first week in July. Samples for yield determinations were obtained about mid-July, when the alfalfa was in the early bloom stage. The remaining plot area was harvested for hay. A second harvest was made about mid-September. The July samples were separated into alfalfa, broadleaved weeds, and weedy grasses, oven-dried and weighed. Only the alfalfa from the September harvests was dried and weighed.

Results and Discussion

The data for 1957 and 1958 represent rather extreme conditions of weed hazards in legume seedings. The area seeded in 1957 was heavily infested with green and yellow foxtails and had a very sparse population of broadleaved weeds. The area seeded in 1958 had an extremely heavy infestation of pigweed with only a few scattered plants of weedy grasses. Improvement of stand of alfalfa was clearly associated with reduction of competition from the predominant type of weeds (Tables 1 and 2). In 1957, the plots where treatments gave no grass control had stands af alfalfa essentially similar to the check. In 1958, where there was no broadleaved weed control the alfalfa stands were the same as those in

the check plots. Although there was a rather wide spread between check and best treatment each year there was close agreement among checks between years.

Table 1. Effects of 4–(2,4–DB), dalapon and combinations of the two on the stand of five varieties of alfalfa in 1957.

Treatment	Rate lb/A	Number of stems in 16 sq ft					
		Buffalo	Grimm	Ladak	Ranger	Vernal	Av
4–(2,4–DB)	1	250	204	235	209	213	222
4–(2,4–DB)	4	193	156	191	196	216	190
Dalapon	2	334*	312	234	315	324	304
Dalapon	8	394*	561**	324	324	470	415**
4–(2,4–DB) + dalapon	1 + 2	313	392	364	370	430	374*
4–(2,4–DB) + dalapon	2 + 4	309	376	282	343	290	320
4–(2,4–DB) + dalapon	4 + 8	299	306	302	360	373	328
Check		183	248	240	191	228	218
Average		284	319	271	288	318	
Standard error		67	72	71	94	106	61

*Difference from check exceeds .05 level of significance.
**Difference from check exceeds .01 level of significance.

Although the herbicides used in this experiment had had little detrimental effect on Ranger alfalfa (4, 5), other varieties might be injured. No variety was injured in 1957 by the herbicides (Table 1). However, in 1958, 4–(2,4–DB) at 4 lb/A plus 8 lb/A of dalapon gave a fairly uniform reduction in stand on all varieties (Table 2). Although the data indicate significant increases in stands for Buffalo and Grimm due to reduction of competitive vegetation, the same trend is observed with the other varieties but at a slightly lower level of significance. Averages of the five varieties show increases in stand each year where herbicides had controlled the predominant weeds.

Stand counts taken early in the summer gave good indications of the effectiveness of herbicide treatment, but yields from clipping told a more complete story. The two different types of weed com-

Table 2. Effects of 4–(2,4–DB), dalapon, combinations of the two, and hand-weeding on the stand of five varieties of alfalfa in 1958.

Treatment	Rate lb/A	Number of stems in 16 sq ft					
		Buffalo	Grimm	Ladak	Ranger	Vernal	Av
4–(2,4–DB)	1	248*	320**	300	248	324	288**
4–(2,4–DB)	4	232	292	289	265	340	284**
Dalapon	2	179	223	194	203	258	211
Dalapon	8	180	200	182	214	274	215
4–(2,4–DB) + dalapon	1 + 2	228	289	274	288*	326	281**
4–(2,4–DB) + dalapon	2 + 4	246*	275	231	216	278	249*
4–(2,4–DB) + dalapon	4 + 8	128	119**	106**	99**	151**	121**
Check		170	223	240	224	282	228
Handweed broadleaved		272**	312*	275	276	302	287**
Handweed grasses		158	231	207	178	252	205
Handweed both		250*	301*	259	228	302	268**
Standard error		35	35	31	32	30	8

*Difference from check exceeds .05 level of significance.
**Difference from check exceeds .01 level of significance.

petition during the successive years of the experiment are clearly brought out by the yields in Table 3. In 1957, the larger yields of alfalfa were associated with the treatments giving grass control. Where there was only broadleaved weed control the grass population was as heavy as in the check or only slightly less. In 1958, control of weedy grasses alone resulted in no benefit to the alfalfa and yields of alfalfa were similar to those of the check. Where broadleaved weed control was most effective in 1958 the yield of

Table 3. Pounds of dry matter per acre of five alfalfa varieties as affected by weed control treatments.

Treatment	Rate lb/A	Lb/A dry matter 1957			Lb/A dry matter 1958			Av
		July	Sept.	Total	July	Sept.	Total	
4-(2,4-DB)	1	120	380	500	950**	1960**	2910	1700
4-(2,4-DB)	4	170	350	520	900**	1680**	2580	1550
Dalapon	2	330	510	840	430	990	1420	1130
Dalapon	8	380*	610*	990	310	860	1170	1080
4-(2,4-DB) + dalapon	1 + 2	640**	770**	1410	870**	1920**	2790	2100
4-(2,4-DB) + dalapon	2 + 4	610**	840**	1450	570	1740**	2310	1880
4-(2,4-DB) + dalapon	4 + 8	530**	680**	1210	260	1300	1560	1380
Check		230	330	560	330	920	1250	910
Handweed broadleaved					840**	1410**	2250	
Handweed grasses					400	930	1330	
Handweed both					860**	1880**	2740	
Standard error		57	115		137	191		

*Difference from check exceeds .05 level of significance.
**Difference from check exceeds .01 level of significance.

alfalfa was more than double that in the check plots. The yields of the hand-weeded plots were nearly identical with those obtained by chemical treatment. The only exception was the combination of herbicides at the heaviest rate which caused considerable loss of stand. Otherwise, the herbicides had little or no adverse effect on the alfalfa.

Although stands of broadleaved weeds were fairly sparse in 1957, there was still a considerable quantity of material produced on the check and dalapon plots (Table 4). Control of the broadleaved

Table 4. Effects of 4-(2,4-DB), dalapon, combinations of the two chemicals and hand-weeding on the stand and yield of broadleaved weeds.

Treatment	Rate lb/A	No. plants in 16 sq ft			Dry matter lb/A		
		1957	1958	Av	1957	1958	Av
4-(2,4-DB)	1	11**	67**	39	60**	150**	100
4-(2,4-DB)	4	2**	8**	5	10**	10**	10
Dalapon	2	38	237	138	1540	2270	1900
Dalapon	8	31	188**	110	1020	1790	1400
4-(2,4-DB) + dalapon	1 + 2	22	61**	42	80**	80**	80
4-(2,4-DB) + dalapon	2 + 4	18	51**	34	60**	80**	70
4-(2,4-DB) + dalapon	4 + 8	17	16**	16	230**	50**	140
Check		28	322	175	1110	3380	2240
Handweed broadleaved			30**			70**	
Handweed grassed			342			3650	
Handweed both			24**			20**	

*Difference from check exceeds .05 level of significance.
**Difference from check exceeds .01 level of significance.

weeds with 4–(2,4–DB) was effective whether it was used alone or in combination with dalapon. Although dalapon is considered primarily a grass herbicide, at 8 lb/A there was considerable stunting of pigweed as indicated by yield reduction when compared with the lighter rate of dalapon. In 1958 when the weed stand was predominantly broadleaved weeds, 8 lb/A of dalapon reduced the yield of broadleaved weeds to roughly half the amount produced on the checks and plots where the grasses were hand-weeded. There was some reduction from dalapon at 2 lb/A.

In 1957, when the grass infestation was severe, the treatments containing dalapon were very effective (Table 5). The indicated stand reduction does not give nearly as complete a picture of the effectiveness as the yields. At counting time many of the grass plants were showing effects of the treatments but were still showing enough life to be counted. By the time of clipping in July the treatment had been effective and the yields showed the control that had beeen obtained. The dalapon alone or in combination with 4–(2,4–DB) gave excellent control. The check plots and those receiving only 4–(2,4–DB) had dense stands of grass with yields of three to four thousand pounds per acre. In 1958, grass stands were very sparse and significant differences were found only on plots where hand-weeding or 4–(2,4–DB) alone reduced the pigweed competition, which favored the growth of the grass.

Table 5. Effect of 4–(2,4–DB), dalapon, combinations of the two chemicals and hand-weeding on stand and yield of the weedy grasses.

Treatment	Rate lb/A	No. plants in 16 sq ft			Dry matter lb/A		
		1957	1958	Av	1957	1958	Av
4–(2,4–DB)	1	643	12	328	3650	90**	1870
4–(2,4–DB)	4	615	21	318	4060	160**	2110
Dalapon	2	391**	14	202	1100**	10	550
Dalapon	8	339**	2	170	40**	0	20
4–(2,4–DB) + dalapon	1 + 2	342**	22	182	440**	20	230
4–(2,4–DB) + dalapon	2 + 4	416**	8	212	250**	10	130
4–(2,4–DB) + dalapon	4 + 8	368**	15	192	120**	0	60
Check		611	16	314	3180	20	1600
Handweed broadleaved			32			140**	
Handweed grasses			13			9	
Handweed both			15			2	

*Difference from check exceeds .05 level of significance.
**Difference from check exceeds .01 level or significance.

SUMMARY

Five varieties of alfalfa, Buffalo, Grimm, Ladak, Ranger and Vernal, were treated with low and heavy rates of 4–(2,4–DB), dalapon and combinations of the two. Few adverse effects were observed on the alfalfa except in 1958 when 4 lb/A 4–(2,4–DB) plus 8 lb/A dalapon reduced stands of all varieties.

The weed control resulted in more hay on both harvest dates and sometimes an actual improvement in stand of the alfalfa.

The 4–(2,4–DB) gave effective control of the broadleaved weeds at the rates used and the dalapon gave effective control of the

grassy weeds. The combination of the two herbicides gave good control of all weeds present.

Reaction of the alfalfa varieties to weed elimination was the same whether accomplished by hand-weeding or herbicides.

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Control of Bamboo in Puerto Rico by Herbicides[1]

H. J. Cruzado, T. J. Muzik, and W. C. Kennard[2]

Introduction

Bamboos are perennial grasses which exhibit great variation in culm height and diameter and are among the most widespread and useful plants in the tropics. More than fifty bamboo genera have been recognized, and the total number of described species and varieties throughout the world is probably near 1000 (7). In India, this plant is considered the poor man's timber (1), and it is an irreplaceable basic material for millions of people in the Orient and in South and Central America (2) (5). Many species are extremely vigorous, however, and become pests when they invade cultivated areas such as coffee farms, lawns, pastures, and sugarcane fields. In some localities, bamboo growth is so rampant as to interfere with the reproduction or development of valuable tree species, and measures must be taken to keep it in check.

The mechanical eradication of mature bamboo clumps is an expensive and tedious operation. If all the culms in a clump are cut, new growth occurs the next rainy season. Experiments carried out elsewhere showed that regrowth was much the same when the bamboo forest was felled during each month of the year (4). Tractors have been used for clearing out bamboo, but this is costly and difficult, especially with the larger types.

Since many species of bamboo are very difficult to eradicate mechanically, this station initiated a program to develop means of controlling these plants by the use of herbicides. The trials described in this paper were performed on the grounds of the Federal Experiment Station, Mayagüez, Puerto Rico.

Materials and Methods

The most effective compounds tested were trichloroacetic acid (TCA), 2,2–dichloropropionic acid (dalapon), 3–(p–chlorophenyl) –1,1–dimethylurea (monuron), and 3–amino–1,2,4–triazole (amitrole). Some 20 additional chemicals were tested, but they showed little or no promise and are not reported here.

The species treated were: *Bambusa arundinacea* Retz.; *B. multiplex* (Lour.) Raeusch.; *B. textilis* McClure; *B. tulda* Roxb.; *B. vulgaris* Schrad. ex Wendl.; *Dendrocalamus asper* (Schultes) Baker; *D. membranaceus* Munro; *D. strictus* (Roxb.) Nees; *Gigantochloa apus* (Schult.) Kurz ex Munro; *Phyllostachys bambusoides* Sieb. &

[1]Received for publication Jan. 22, 1960.

[2]Agronomist, Plant Physiologist, and Horticulturist, respectfully, Federal Experiment Station, ARS, U. S. Department of Agriculture, Mayagüez, Puerto Rico. T. J. Muzik's present address is: Department of Agronomy, Washington State College, Pullman, Washington. W. C. Kennard is now in the State Experiment Stations Division, ARS, U. S. Department of Agriculture, Washington, D. C.

Zucc.; *P. meyeri* McClure; and *Sinocalamous oldhami* (Munro) McClure.

The herbicides were applied by three methods, (1) basal applications to intact bamboo culms, (2) basal applications to cut bamboo clumps, and (3) foliage sprays on regrowth of the cut clumps. For basal applications, a watering can was used, and an aqueous solution or suspension of the herbicide was applied to the soil around the culms at the rate of 2 gallons per 50 culms.[3] Foliage treatments were applied with a knapsack sprayer at a rate sufficient to wet the treated plants thoroughly. A surfactant (Tween 20)[4] was added at the rate of 0.05%.

Observations were made at intervals varying between 1 and 24 months on defoliation, dieback, stunting, malformation, chlorosis, regrowth, and death.

EXPERIMENTAL RESULTS

Basal applications to intact bamboo culms. Duplicate intact clumps of 10 bamboo species were treated with TCA, dalapon, and monuron to determine susceptibility. The thin-culm species, *Phyllostachys meyeri,* was treated at the rate of 0.8 pound active ingredient of the chemical per 50 culms. The other species were treated at the rate of 1.6 pounds active ingredient per 50 culms. The height of the mature clumps varied from 12 feet in *P. meyeri* to 70 feet in *B. arundinacea.*

Observations made 9 months after application show that monuron was the most effective herbicide since 10 out of 20 clumps treated were killed with this herbicide. Those killed included all plants of *B. tulda, G. apus,* and *B. textilis. B. vulgaris* (the common bamboo in Puerto Rico) and *Phyllostachys bambusoides* were the most resistant species to action of the three herbicides.

Observations 24 months after treatment (Table 1) showed that the following bamboo species were eradicated by basal application of monuron at the rate of 1.6 pounds of chemical in 2 gallons of water per 50 culms: *B. tulda, B. textilis, G. apus, D. asper,* and *D. strictus. P. meyeri* was more sensitive and was killed at the 0.8-pound rate. *B. textilis, D. asper,* and *D. strictus* also were eradicated with dalapon at the 1.6-pound rate. This herbicide is the most promising compound for eradicating *B. vulgaris* by basal application, since both plants treated showed 100 per cent defoliation, 20 feet dieback, and no regrowth. TCA eradicated both treated plants of *D. strictus,* but the species is very susceptible to herbicides and is the only one that was killed by all three herbicides.

[3]Because of considerable differences in densities of bamboo stands, applications on the basis of number of culms were considered more meaningful than on basis of area occupied.

[4]Polyoxyethylene sorbitan monolaurate manufactured by the Atlas Powder Company, Wilmington, Del.

Table 1. The effect of aqueous basal sprays of three herbicides on 10 bamboo species 24 months after treatment.

Species	Pounds per 50 culms	Herbicides		
		Monuron	TCA	Dalapon
B. arundinacea	1.6	Recovered	Recovered	100% defoliation 20-foot dieback
B. textilis	1.6	Dead	No effect	Dead
B. tulda	1.6	Dead	Stunted	Recovered
B. vulgaris	1.6	Recovered	Recovered	30-foot dieback 100% defoliation
D. asper	1.6	Dead	50% dead	Dead
D. strictus	1.6	Dead	Dead	Dead
G. apus	1.6	Dead	Recovered	Recovered
P. bambusoides	1.6	50% of culms dead	No effect	Recovered
P. meyeri	0.8	Dead	Recovered	75% of culms dead
S. oldhami	1.6	Dead	Recovered	50% dead

Smaller quantities of monuron and TCA (0.4 and 0.8 pounds per 50 culms) also were applied to intact culms of *D. strictus*. These treatments with TCA gave unsatisfactory control, but suggest that monuron still may be effective at these lower rates of application.

Basal applications to cut bamboo clumps. The culms of mature clumps of *B. arundinacea,* about 16 years old and 70 feet high, were cut off 1 to 2 feet above the ground. This species is spiny and is one of the most vigorous types. The herbicides were applied in water around the base of the clumps, from which the dead leaves and other plant residues had been removed, as well as poured over the cut-off culms. At the time of treatment, 2 weeks after cutting, a few of the clumps had small shoots, but the majority of these were without leaves. TCA and monuron were applied at the rate of 0.4, 0.8, and 1.6 pounds per 50 culms. Duplicate clumps were used for each treatment, and readings were taken at frequent intervals for a period of 6 months.

Regrowth was very rapid in the untreated plants, some shoots growing 20 feet within 2 months. In the TCA treatment, the shoots were either completely inhibited or badly malformed. The 1.6-pound rate was the most effective, although the 0.8-pound rate also gave excellent results. There was some growth of shoots at both rates, but these shoots eventually died.

Monuron caused yellowing of the leaves and stunting of growth at all rates. These stunted yellow shoots persisted for several months and finally died. A few clumps of *Dendrocalamus membranaceous* were intermingled with *B. arundinacea* and also were cut and treated with monuron. No regrowth occurred, and all of the clumps died. In one clump of this species, which was only partially cut, the erect culms (50 feet high) also were killed.

The combination of TCA and monuron at the rate of 0.8 and 0.4 pounds, respectively, per 50 culms, gave excellent kill in *Bambusa multiplex* and *Dendrocalamus strictus*.

Foliage sprays. Applications of herbicides also were made to the foliage of nine species of bamboo. Since it was impossible to

Table 2. The effect of aqueous foliage sprays of 3 herbicides on 9 bamboo species 24 months after treatment.

Species	Herbicides[a]		
	Amitrole	Dalapon	TCA
B. textilis	50% dead	Recovered	No effect
B. tulda	Dead	Recovered	Recovered
B. vulgaris	Recovered	Recovered	Recovered
D. asper	Dead	Recovered	Recovered
D. strictus	Dead	50% dead	Dead
G. apus	50% dead	Recovered	Recovered
P. bambusoides	Recovered	Recovered	Recovered
P. meyeri[b]	Recovered	Recovered	No effect
S. oldhami	Dead	50% dead	50% dead

[a]All herbicides applied at concentrations of 6 per cent active ingredients.
[b]A dwarf type; sprayed without being cut.

apply sprays to the foliage of intact culms (some of them reaching a height of 70 feet), all culms were cut near the ground and allowed to regrow. Sprays were then applied to the foliage after culms had regrown to a height of 6 to 8 feet. The species used are listed in Table 2. Duplicate clumps of each species were used for each treatment.

The herbicides TCA, dalapon, and amitrole were applied in a 6-per-cent-active-ingredient aqueous solution to which 0.05 per cent Tween 20 was added. Sufficient spray was applied by means of a knapsack sprayer to wet the leaves thoroughly.[5]

Observations made 9 months after treatment showed that *D. strictus* and *S. oldhami* were the most susceptible species to the herbicides used. Five of six treated clumps of *D. strictus* and four of *S. oldhami* were dead or badly injured. Amitrole killed both species. As in the basal treatment, *B. vulgaris* and *P. bambusoides* were the most resistant species. Observations 24 months after treatment are shown in Table 2.

In these experiments the possibility existed that some of the herbicides could have fallen to the ground and injured the bamboo by absorption through the roots. Therefore, the test was repeated, protecting the soil around the bases of the bamboo species with heavy brown paper during the spray operation. Clumps of both *B. tulda* and *D. strictus* were used. Observations made 6 months after treatment showed no consistent difference between protected and unprotected clumps. *D. strictus* appeared to be more sensitive than *B. tulda* to all of the herbicides applied.

Since it was found that amitrole was very effective when sprayed on the foliage and monuron when sprayed to the base of bamboo species, and since dalapon was the most promising herbicide for controlling *B. vulgaris,* another experiment was undertaken in an

[5]The amount of spray applied depended on the size of the new growth and varied from as little as 200 cc. of solution for the smaller clumps to as much as 2,000 cc for the larger.

effort to control this latter species with some herbicidal combinations.

Four bamboo clumps were cut 1 to 2 feet above the ground level approximately 2 months before treatment. At the time of treatment the new growth had reached a height of 5 to 7 feet.

Amitrole (3 per cent) in combination with monuron (6 per cent) or with dalapon (6 per cent) was applied in an aqueous suspension or solution to which 0.05 per cent Tween 20 was added. The ground under the plants was cleaned of dead leaves and other plant residues and sufficient spray was applied by means of a knapsack sprayer to wet the leaves and stems thoroughly and to cause some run-off. Observations 9 and 24 months later are given in Table 3. Clumps

Table 3. Effect of combinations of some herbicides applied as foliage sprays to new growth from cut culms of *Bambusa vulgaris.*

Treatment	Culms per clump	Liters solution applied	Effect of treatment	
			After 9 months	After 24 months
Monuron (6 per cent) + Amitrole (3 per cent)	96	8	Plant stunted. No regrowth. Nodes malformed with branches of whitish leaves.	Plant stunted. 90% of stumps dead. Rest with stunted side branches. One small thin shoot.
	60	6	One culm green with a new shoot. Other culms yellow. Nodes malformed with bunches of whitish leaves.	Recovering slowly 1 big new shoot. 3 thin unhealthy shoots.
Dalapon (6 per cent) + Amitrole (3 per cent)	40	5	Plant dead	Plant dead
	55	6	Plant dead	Plant dead, with some stumps already uprooted.
Check	50	0	Culms green, completely covered with dense green foliage. Eight new shoots, 3 of them 20 feet high.	Most culms green with dense green foliage. Ten new shoots about 25 feet high.

of *B. vulgaris,* when cut and allowed to start regrowth, were highly susceptible to dalapon when applied to the foliage in combination with amitrole (Figure 1).

DISCUSSION

The experiments show different susceptibilities to herbicides among bamboo species. The well-known solid bamboo, *Dendrocalamus strictus,* was the most susceptible of the species tested and was easily eradicated with herbicides. The most resistant species were the running-type bamboo, *Phyllostachys bambusoides,* and the so-called common bamboo, *Bambusa vulgaris.* Even these species were controlled with herbicides; although retreatment, or combinations of herbicides may sometimes be necessary. The other species were intermediate in tolerance.

The first symptom of toxicity of amitrole when applied to foliage was defoliation of the sprayed plant. The leaves that developed afterwards were apparently deficient in chlorophyll and the other plastid pigments. Investigations on potatoes and barley (3) showed

Figure 1. A cut *B.* vulgaris clump 2 years after application of a foliage spray consisting of 6 per cent dalapon + 3 per cent amitrole in aqueous solution. Intact plants in the background were not treated, but culms around man were sprayed two months after being cut.

that this deficiency was the effect of catalase and chlorophyll depression by amitrole. Complete stunting, followed by death of the plant, finally occurred.

Observations were made over a sufficiently long period of time to be certain that regrowth did not occur. These results indicate that various aggressive bamboo species can be eradicated by the application of herbicides to the bases of culms or sprays to regrowth foliage. It should be pointed out, however, that even though clumps of bamboo are killed, some of them—notably *D. strictus, D. asper,* and *B. vulgaris*—decay slowly and may remain to make reuse of the land difficult for a considerable period of time.

SUMMARY

The effectiveness of herbicides in eradicating unwanted bamboo in Puerto Rico was investigated. Some 25 different compounds were tested on a total of 12 species of bamboo, representing 5 genera. Among the most effective treatments were the application of monuron, TCA, and dalapon to the bases of intact or cut bamboo culms and amitrole as a spray to regrowth foliage. Combinations of these herbicides were found to be most effective on the common bamboo, *B. vulgaris.* For highly resistant species, a second treatment was necessary.

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Soil-Moisture Retention and Snow-Holding Capacity as Affected by the Chemical Control of Big Sagebrush (*Artemisia tridentata* Nutt.)[1]

LESLIE W. SONDER and HAROLD P. ALLEY[2]

CONTROL of big sagebrush (*Artemisia tridentata* Nutt.) with fire, chemicals, or mechanical means has long been recognized as an effective method for rangeland improvement. If this sagebrush is killed or weakened by some method of control, excellent stands of grass may be obtained if all conditions are favorable (7). Bohmont (3) states that as the percentage of sagebrush control increases, the grass and grasslike species also increase.

Blaisdell (2) writes that knowledge of the effects of competition between sagebrush and native grasses is one of the basic requirements for an adequate study of the areas dominated by big sagebrush. The available moisture in soil is the most important factor in western range-forage production.

Robertson (7) writes that even though sagebrush spreads and disperses a large amount of rain and snow, the competition for soil moisture is believed to be more important.

The amount of evaporation lost is relative to the quantity of precipitation intercepted; it varies with the kind of vegetation and the type and size of storm. Measurements show that interception loss is usually between 5 and 15 percent of the annual rainfall and is found to be fairly constant, under the same vegetative conditions, at various locations (1). Thinning or changing the vegetation so as to reduce the total volume of the canopy will reduce the water loss due to interception. Additional water may be delivered to the ground without damaging consequences, if the changing of the canopy does not seriously lower the protection provided to the soil by the vegetation (6).

Hyder and Sneva (5), in reporting results of chemical control of sagebrush in Oregon three years after treatment, state that highest grass yields were obtained the first year after treatment, and yields decreased a little in each of the next two years. The response from sagebrush control may also be a release from competition for soil nitrogen as well as soil moisture. Experimental results also showed that on sagebrush bunchgrass range there is an evident change in competition at different soil-moisture levels the first year after treatment. They concluded that the sprayed areas also improved the moisture relations by better retention of precipitation, but that moisture depletion was faster on the treated than on untreated areas.

In a study by Robertson (8) concerning the degrees of competition between range grasses and sagebrush, it was noted that the sage-

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[2]Graduate Research Assistant, University of Wyoming, Plant Science Division and Assistant Professor, Plant Science Division, University of Wyoming, Laramie, respectively.

brush plant acts as a "black body" radiator and evidently hastens melting and evaporation of snow. This increased rate of snow melt is apparently responsible for the fact that the grasses in his sagebrush areas started their spring growth two weeks earlier than the same species in cleared areas or in strips in which the brush had been sprayed.

Sagebrush intercepts and holds snow increasing the total surface area of the snow. Snow is released from the vegetation by wind or melt. There is often an abundant evidence of both: either drifts form or the snow is pitted beneath the brush from water droplets (1). The melting of snow from shrubby vegetation just before freezing weather may result in the formation of a layer of ice on top of the soil. Forsling (4) states that a layer of ice on the surface of the soil will increase the run-off from the area.

Storey (9) writes that a cover of vegetation and snow has a large influence upon the extent, the persistence, and the movement of frost into the soil. A light new snow provides an insulation which tends to retard soil freezing. A 24-inch layer of snow will prevent frost penetration in severe weather. Even though the ground was frozen before the first snowfall, when snow depth reaches 18 to 24 inches, further freezing ceases.

Studies by Forsling (4) show that there is often no frost in the soil when the ground has been continually blanketed during freezing periods. When the soil contains only a shallow frost it may thaw under blanket of snow and absorb water as melting takes place.

This study was undertaken to determine any differences in the soil-moisture percentage at various soil depths between controlled and uncontrolled sagebrush areas, and to determine the effect of sagebrush control on the snow-holding capacity of the areas.

METHODS

The two areas used for experimental study are located in the Big Horn Mountains of North Central Wyoming and in the Red Desert of South Central Wyoming.

The Big Horn Mountain area has an elevation of 8,200 feet and an average annual precipitation of 20 inches. The original treatments were applied in 1952 and 1953, the amount of sagebrush control varying from 0 to 100 percent as a result of the various chemical treatments.

The Red Desert area has an elevation of 7,000 feet and an average annual precipitation of 10 inches, most of which falls as snow. The plots were treated with butyl ester and propylene glycol butyl ether ester formulations of 2,4–D in June of 1957. Various width unsprayed buffer strips were left between each sprayed area.

In the Big Horn experimental areas, three 100 percent sagebrush-controlled areas and three uncontrolled areas were selected at random for conducting soil-moisture studies. Four sites were selected at random on the 80 to 100 percent controlled and the uncontrolled areas on the Red Desert area.

In both of the areas at each of the station locations, random soil samples of uniform soil type were collected from the surface inch and from depths of 6–7, 12–13, and 18–19 inches. The samples were placed in closed metal containers, taken to the laboratory, weighed, oven-dried at 105°C for 24 hours, and the percentage of moisture in the soil determined.

A second method for determining the relative moisture of the soil was the use of Bouyoucos moisture-absorption blocks. These plaster of paris blocks were placed in the soil in July 1958, at Hyattville and August 1958 in the Red Desert, at depths of 6, 12, and 18 inches, the depths being replicated five times at each of the stations.

Snow surveys were conducted in the Red Desert and Hyattville areas in 1958 and were continued until April 1959. Snow-depth and soil-moisture measurements were taken along a mapped course across each of the treated and untreated strips. Ten measurements and samples were taken on the treated and untreated strips.

RESULTS

Red Desert soil-moisture studies.

Soil-moisture studies made one year after initial chemical treatment indicate that areas of 80 to 100 percent sagebrush control retain more soil moisture than do the untreated areas. The chemically controlled areas retained a significantly higher percentage of moisture at the 6–7, 12–13, and 18–19 inch soil depths than the non-controlled areas. The largest difference in moisture was found to occur at the depth of 18–19 inches. The average difference in total moisture between the controlled and uncontrolled sagebrush areas, regardless of depths, was 1.7 percent, which is significant at the one percent level of probability (Table 1).

Table 1. Average moisture percentages at various depths in soils on the Red Desert in 1958.

Date of sampling	Soil depth, inches									
	0–1	6–7	12–13	18–19	Av.	0–1	6–7	12–13	18–19	Av.
	Per cent soil moisture where the sagebrush control was									
	80–100%					0%				
July 20	1.8	6.9	9.2	9.8	6.9	1.2	3.8	6.8	5.5	4.3
August 21	3.3	5.5	6.1	5.9	5.2	2.3	5.9	5.5	4.7	4.6
September 28	2.4	6.2	6.5	7.3	5.6	2.2	4.5	4.2	4.1	3.7
Average	2.5	6.2	7.3	7.7	5.9	1.9	4.7	5.5	4.7	4.2

LSD, per cent control between dates at .05 = 1.9, at .01 = 2.6.
LSD, per cent sagebrush control over all depths at .05 = 0.5, at .01 = 0.9
LSD, soil depth between per cent sagebrush control at .05 = 1.5, at .01 = 2.2.

Data show that at the 18–19 inch soil depth there was a difference of 3 percent soil moisture between the controlled and uncontrolled sagebrush areas during the summer of 1958 (Table 1); therefore, the controlled area actually contained 63.8 percent more soil mois-

ture than the uncontrolled area. The greatest moisture difference was observed at the sampling date in July, with an average difference of 3.1 percent at the 6–7 inch depth, 2.4 at the12–13 inch depth, and 4.3 percent at the 18–19 inch level, with the controlled area containing the higher percentage of soil moisture.

The chemically controlled sagebrush plots exhibited a sharp drop in soil moisture from July 20 to August 21 with a slight increase in moisture content from August 21 to September 28; however, the live-sagebrush areas exhibited a steady decline in moisture percentage from July through September (Table 1). A significantly higher amount of moisture was found in the controlled areas on July 20 and September 28, with the percentage of moisture approximately the same on August 21 for the two areas.

The Bouyoucos resistance block readings of September 28, 1958 indicated that both areas were beyond 15 atmospheres of tension, which is recognized as an average tension of the "permanent wilting point" of most plants.

In June and July 1959, two years after treatment, a significantly higher percentage of soil moisture was found at the 12–13 inch and the 18–19 inch depth in the controlled area when compared with that of the uncontrolled sagebrush area. The controlled area contained 26.6 percent (a difference of 2.4 percentage points) more soil moisture at the 12–13 inch depth and 34.7 percent (a difference of 3.2 percentage points) more soil moisture at the 18–19 inch depth than the uncontrolled sagebrush area on June 8, with no appreciable difference noted at any depth in July (Table 2).

Table 2. Average moisture percentages at various depths in soils on the Red Desert in 1959.

Date of sampling	Soil depth, inches									
	0–1	6–7	12–13	18–19	Av.	0–1	6–7	12–13	18–19	Av.
	Per cent soil moisture where sagebrush control was									
	80–100%					0%				
June 8	1.6	9.5	11.4	12.4	8.7	1.1	9.2	9.0	9.2	7.1
July 15	1.4	7.9	7.9	8.0	6.3	1.6	7.8	7.0	6.8	5.8
Average	1.5	8.7	9.7	10.2	7.5	1.4	8.5	8.0	8.0	6.5

LSD, per cent control between dates at .05 =0.7, at .01 =1.0.
LSD, soil depth between per cent sagebrush control at .05 =1.0, at .01 =1.4.

In June and July of 1959, there was a significant difference of 3.3 atmospheres in soil-moisture tension between the controlled and uncontrolled areas. The controlled area had the lower tension showing that a higher percentage of moisture was retained than on the uncontrolled area (Table 3).

Red Desert snow study.

Comparison of snow depth between the chemically controlled and the uncontrolled big-sagebrush areas showed no significant difference in the amount occurring at any period during the study.

Table 3. Average soil-moisture tension in soils on the Red Desert in 1959.

Date of sampling	Soil depth, inches							
	6–7	12–13	18–19	Av.	6–7	12–13	18–19	Av.
	Percent soil moisture tension where sagebrush control was							
	100%				0%			
June 8	1.00	0.74	0.87	0.87	1.00	0.98	0.84	0.96
July 15	7.30	5.90	6.40	6.50	15.00	13.60	10.50	13.00
Average	4.20	3.40	3.60	3.70	8.00	7.30	5.70	7.00

LSD, between percent control at .05 =1.36, at .01 =1.83.
LSD, soil depth between percent sagebrush control at .05 =2.35, at .01 =3.15.
LSD, percent control between dates at .05 =1.36, at .01 =1.83.

The snow cover was observed to be very even over the entire area except where occassional small clumps of tall sagebrush occurred. During the study, the controlled and uncontrolled areas were covered with an average depth of 7.7 inches of snow, containing 2.3 inches of water.

The various widths of controlled and uncontrolled strips had no influence upon the amount of snow held in them or in the strips to the windward side.

Big Horn soil-moisture studies.

Moisture-retention studies of the Hyattville and Baldridge big-sagebrush experimental areas six years after the initial chemical treatment for control of big sagebrush indicated that a small difference in soil moisture existed between the 100 percent chemically controlled and the 0 percent controlled areas. However, when the factors of depth and date were disregarded, analyses showed no significant difference between the controlled and uncontrolled area (Tables 4 and 5), even though the 100 percent controlled sagebrush area near Hyattville contained 18.2 percent more soil moisture than the untreated area, and the 100 percent controlled area at Baldridge contained 6.2 percent more soil moisture than the untreated area.

Statistical analyses of data obtained shows that the 100 percent controlled sagebrush areas, at both locations, contained a significantly higher percentage of moisture than the untreated areas on July 30, 1958. A difference of 4.6 (Table 4) percentage points in soil moisture was found between the controlled and uncontrolled areas at Hyattville and a difference of 2.7 (Table 5) percentage points existed between the areas at Baldridge. These differences are significant at the 1 percent level of probability.

Soil moisture percentages (Table 4 and 5) in the controlled and uncontrolled areas show that soil-moisture decline is not the same for the different dates and depths on these two areas. The uncontrolled area at Hyattville lost 33.6 percent more moisture than the controlled area from June 25 to July 30. The greatest loss of moisture during this period was at the 6–7 and 12–13 inch soil depths on the uncontrolled area (Table 4). The moisture loss

Table 4. Average moisture percentages in soils on Hyattville plots in 1958.

Date of sampling	Soil depth, inches									
	0–1	6–7	12–13	18–19	Av.	0–1	6–7	12–13	18–19	Av.
	Percent soil moisture where sagebrush control was									
	100%					0%				
June 25	36.4	23.9	19.3	18.9	24.6	32.9	21.4	19.9	16.9	22.6
July 30	39.0	17.9	11.7	10.5	19.8	35.0	9.7	7.7	8.2	15.2
August 30	8.6	8.9	7.7	7.3	8.1	7.5	7.4	6.2	5.7	6.7
Average	28.0	16.9	12.9	12.2	17.5	25.2	12.8	11.2	10.3	14.8

LSD, Percent control between dates at .05 =2.7, at .01 =3.7.

from July 30 to August 30 is just the reverse of this, the controlled area losing 26.0 percent more moisture than the uncontrolled area, largely because of a decrease from 17.9 to 8.9 percent moisture or a 50 percent loss in the amount of soil moisture at the 6–7 inch depth.

Table 5. Average moisture percentages in soils on Baldridge in 1958.

Date of sampling	Soil depth, inches									
	0–1	6–7	12–13	18–19	Av.	0–1	6–7	12–13	18–19	Av.
	Percent soil moisture where sagebrush control was									
	100%					0%				
June 25	45.2	29.8	26.5	25.2	31.7	49.6	28.9	23.8	20.7	30.7
July 30	44.7	27.2	24.7	16.6	28.3	38.4	29.0	18.7	16.2	25.6
August 30	17.0	12.2	12.2	15.9	14.3	16.3	11.8	13.3	12.3	13.4
Average	35.6	23.1	21.1	19.2	24.8	34.8	23.2	18.6	16.4	23.2

LSD, percent control between dates at .05 =1.5, at .01 =2.1.

In the experimental area at Baldridge, there was only a slight difference in soil moisture at all soil depths in both the controlled and uncontrolled areas from June 25 to July 30 (Table 5). However all soil depths within both areas of control, showed a considerable loss from July 30 to August 30, except for the 18–19 inch soil depth in the controlled area, where the loss of soil moisture occurred at the 18–19 inch depth in July with very little loss of moisture in August.

Readings taken from the Bouyoucos blocks at the Hyattville location showed a significantly lower soil moisture tension in the 100 percent controlled area. This difference was found mainly at 18–19 inches (Table 6). This indicates that the controlled area contained a higher percentage of moisture than the uncontrolled area.

Data collected on July 9, 1959, using both soil samples and soil-moisture tension, showed no significant difference between the controlled and uncontrolled areas at both locations in the Big Horn Mountain study.

Table 6. Average soil-moisture tension of areas on Hyattville plots on August 30, 1958.

Soil depth inches	Percent soil-moisture tension where sagebrush control was	
	100%	0%
6	1.9	2.2
12	1.5	2.0
18	2.2	3.4
Average	1.9	2.5

LSD, percent sagebrush control over all soil depths at .05 =0.6, at .01 =0.8.
LSD, soil depth between percent sagebrush control at .05 =1.1, at .01 =1.5.

Big Horn snow study.

Snow surveys made in April 1958 and May 1959 of the chemically controlled big-sagebrush plots in the Big Horn Mountains, an area where very little drifting of snow occurs, indicated that areas of 100 percent control retained snow later in the spring than areas of no control. On April 10 1958, there was an average snow depth of 23.7 inches containing 6.9 inches of water on the 100 percent chemically controlled areas and 7.7 inches containing 2.5 inches of water on the 0 percent control.

On the uncontrolled areas the ground was frozen and covered with an ice sheet approximately two inches in thickness, but on the chemically controlled areas these conditions were absent, and the surface of the soil was found to be quite mellow. The soil surface immediately around live sagebrush plants was completely bare. This condition may be caused by the greater canopy of live sagebrush providing more evaporative areas as well as the "black body" radiator effect. The chemically controlled areas were observed to have a very even depth of snow with complete absence of bare areas.

The measurements made on May 2, 1959, showed that the controlled areas held an average of 9.8 inches of snow containing 3.4 inches of water compared with the live sagebrush area which held 8.3 inches of snow containing 2.1 inches of water. One of the uncontrolled plots was completely devoid of snow, but a 100 percent control plot next to it was still partially covered with snow (Fig. 1).

CONCLUSIONS

1. Eighty to 100 percent sagebrush-control areas in tha Red Desert experimental area, retained a significantly higher percentage of soil moisture one year after chemical control than uncontrolled areas.
2. Six years after chemical control, 100 percent control areas in the Big Horn Mountains contained a significantly higher percentage of soil moisture in late July than the uncontrolled areas.
3. Sagebrush control had no effect upon the snow-holding capacity in the Red Desert area in south-central Wyoming where drifting of snow usually occurs.

Figure 1. Top unsprayed sagebrush area completely devoid of snow on May 2, 1959: bottom, sagebrush 100 percent controlled area partially covered with snow on the same date.

4. Controlled sagebrush areas in the Big Horn Mountain region retained snow longer in the spring of the year than uncontrolled areas.
5. The various-width sagebrush strips, in regions where drifting usually occurs, did not have a measurable effect upon the snow-holding capacity.

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A Device for Subsurface Application of Herbicides[1]

O. B. Wooten and C. G. McWhorter[2]

It has been only in comparatively recent years that any appreciable work has been conducted on equipment for the application of chemicals in the soil. Most of the early work was devoted primarily to methods of applying anhydrous ammonia and liquid solutions as fertilizers. In most of this work the principal injection tool consisted of a chisel-type applicator that released the chemical at a single point in the soil. In recent years, investigators have attempted to devise efficient and uniform methods of subsurface distribution. Hedman and Turner (3) reported on a chisel-type applicator equipped with a "fishtail" to give more lateral spread to anhydrous ammonia. Arya and Pickard (1) studied the effect of high pressures and velocities on the application of anhydrous ammonia, which was also single-point injection. Certain problems associated with the application of fungicides and herbicides in the soil have been discussed by Owen (4) and Becker and Costel (2).

In recent studies at the Delta Branch, Mississippi Agricultural Experiment Station, existing equipment was inadequate for the application of volatile preplanting herbicides. Discs were used to incorporate surface-applied herbicides in the soil, but this method resulted in poor mixing (5) and destroyed the row profile when used in prepared seedbeds.

In an attempt to improve the method of distribution, a horizontal-blade applicator was constructed to apply herbicides underneath the soil surface. This device was designed to apply and mix the chemical in the soil in one operation. The design criteria for development of the applicator were as follows:

1. The applicator should be capable of applying the chemical in a well-defined pattern at various depths in the seedbed.
2. Variation in band width should be obtainable by changing orifices.
3. Passage of the applicator through the bed should not collapse the row profile to the extent that rebedding would be necessary.
4. The applicator should be a simple attachment to an existing sprayer rather than a complete machine.
5. The applicator should be simple to operate and free of complicated adjustments.

Description of applicator. The applicator developed was of two-piece construction. Each end of the bottom horizontal cutting blade was turned up at a 90° angle to form the attaching members.

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[2]Agricultural Engineer, Agricultural Engineering Research Division, Agricultural Research Service, United States Department of Agriculture, and Plant Physiologist, Crops Research Division, Agricultural Research Service, United States Department of Agriculture, and the Mississippi Agricultural Experiment Station. The work described was done in cooperation with the Delta Branch. Mississippi Agricultural Experiment Station, Stoneville, Mississippi.

A concave blade was fitted horizontally to the cutting blade between the vertical end members, beginning at a point 1 inch to the rear of the leading edge of the bottom blade (Figure 1). The inside angle was welded and formed by the two blades so that soil could flow smoothly over the top surface. A small spray boom was placed in the angle formed by the two horizontal blades of the applicator.

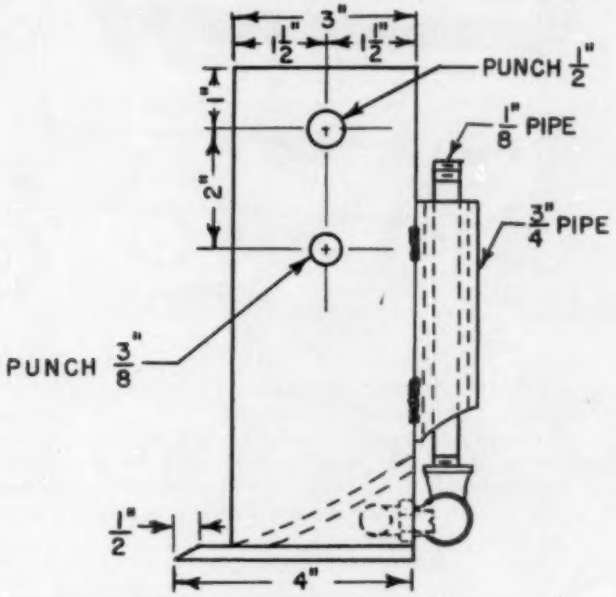

Figure 1. Side view of applicator.

The overall width of the applicator was 20 inches and adjustments were provided for use with row spacings ranging from 36 to 42 inches. The vertical ends of the blade contained two holes so that the applicator could be attached to regular sweep standards. Shear bolts were used in the lower holes as protection for the device. The applicator standards were attached to the cultivator gang beams with standard clamps.

Quick-change booms were fabricated from ⅛-inch pipe to accommodate one, two, and three orifices. The orifices faced to the rear of the direction of travel of the applicator (Figure 2). Different angles of application could be obtained by simply rotating the boom.

Figure 3 shows the applicator in the working position in the bed. The concave surface of the blade, when in forward motion, produced a mobile umbrella of soil under which the spray pattern could pass undisturbed from one or more nozzles in the spray

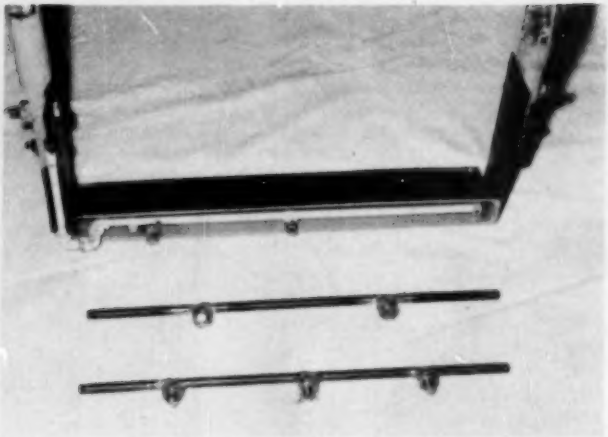

Figure 2. Underground chemical applicator and attaching standards, fitted with single orifice; 2-outlet and 3-outlet booms are shown in the foreground.

boom. Collapse of the umbrella shortly after passage of the blade trapped the herbicide under the surface of the soil.

Test machine. A two-row, rear-mounted cultivator was used as the basic carrier for the applicators. Each gang beam floated on parallel linkage but the beams on each individual row were fastened together rigidly by the applicator. A gauge wheel was behind and in the center of each unit for the purpose of controlling the operating level of the applicator.

The applicator was mounted forward on the gang beams. Ample

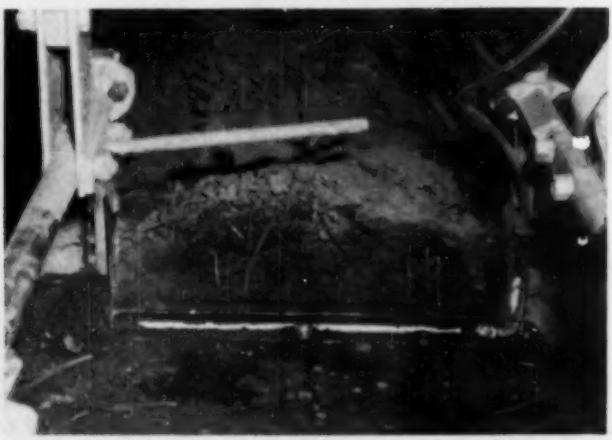

Figure 3. Cross-section of bed showing applicator in working position.

space was allowed to the rear of the applicator for ground-working implements which can be used to further distribute or mix the herbicide and soil. Figure 4 shows a combination of the underground applicator and rotary hoes. Each applicator was supplied with liquid from an individual hose passing through a flowrator meter. Although the rate of flow was measured, the primary use of the meter was to indicate stoppage at each individual nozzle. The float at rest at the bottom of the tube indicated a completely clogged nozzle. The tank, pumps, and other components were the same as those used for conventional herbicide applications.

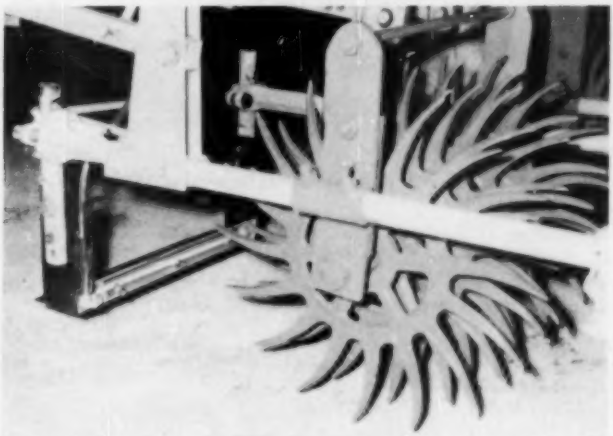

Figure 4. Underground applicator followed by rotary hoe section. Hoes are operated in reverse direction.

Orifice types. Orifices which produced square and circular spray patterns were used in an attempt to obtain a vertical spread of the material applied in the bed. The soil flowing over the trailing edge of the applicator blade squeezed these patterns into a thin horizontal line producing patterns similar to a fan-type spray when applied horizontally. Underground patterns produced with the several types of orifices were evaluated by using the fluorescent material and ultraviolet light technique described by McWhorter and Wooten (5).

A horizontally-positioned, double-outlet, fan-type orifice with a spray angle of 150° produced a ¼-inch thick band approximately 16 inches in width at 40 psi. The positions and types of nozzle are shown in Figure 5. This pattern was selected for testing the efficiency of underground spray application in the first trials.

Test for efficiency. A test was conducted using the 150° fan orifice at 40 psi. The herbicide ethyl *N,N*–di–*n*–propylthiolcarbamate (EPTC) was applied in a 16-inch band at the broadcast volume of 40 gallons per acre. Placement variables included depth

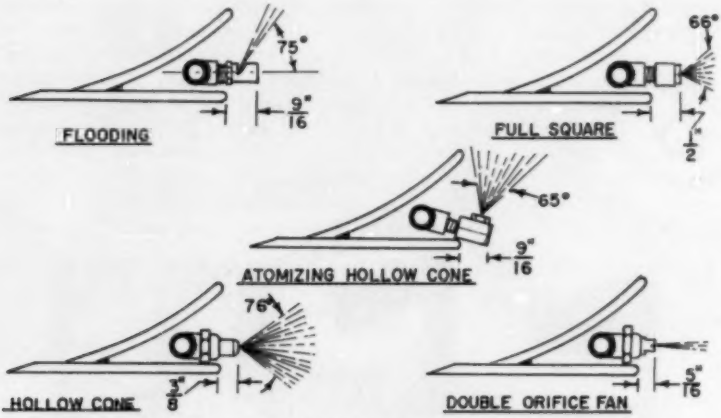

Figure 5. Orifice types and locations in underground applicator.

of application and disturbance or nondisturbance of the soil after initial placement of the herbicide. The exact variables and the data obtained are presented in Table 1. The herbicide was applied March 30th and the cotton was planted May 19th.

Table 1. Stands of cotton and weed control ratings obtained following the application of preplanting treatments with EPTC at 5 lb/A on March 30, 1959, cotton was planted May 19, 1959.

Method of application of herbicide	Plants per acre June 4 thousands	Weed control ratings June 15[a]	Hoe labor per acre June 22 hours
Underground 2 inches[b]	32	9.0	6.1
Underground 6 inches[b]	48	9.0	5.4
Underground 2 inches,[b] rotary hoed	38	8.4	6.7
Soil surface, rotary hoed	50	7.4	14.6
No herbicide applied	52	0	17.8

[a]No control = 0, perfect control = 10.
[b]Depth from top surface of undisturbed bed.

In the initial trials, a higher degree of weed control was obtained with the material when applied underground than with surface application. Mixing after subsurface application had little effect in this test. This indicates that a lower rate of material could be used satisfactorily if applied underground than that required for surface application.

General notes on performance. The applicator worked satisfactorily in several loam soils, but scouring was a problem in a heavy clay soil. Bed collapse was not a problem with equipment operating at speeds up to 5 mph.

Bands of material were deposited in the bed at depths ranging from 2 to 6 inches with this device. Any desired band width up

to 16 inches was obtained by using fan-type orifices of different spray angles.

Uniform mixing of the chemical in the upper part of the bed after initial application was accomplished successfully in several loam soils, provided the moisture content of the soil was field capacity or less. A rotary-hoe attachment, with the tines operating in reverse position, was used for the mixing operation immediately behind the applicator.

The depth of the applicator was controlled so that the tines of the rotary hoe passed through the treated band. This tended to bring the chemical toward the surface, thereby giving distribution in that portion of the bed lying above the treated band. The initial investigations indicate that chemicals other than herbicides can be applied in several ways with the device.

Summary. A device for the underground application of herbicides was designed and tested. Through the use of this device the investigators were able to place a ¼-inch thick, 16-inch wide band of spray material from 2 to 6 inches under the soil surface. In subsequent evaluation of the device, much better weed control was obtained with subsurface application of the herbicide (EPTC) than with surface application of an identical rate.

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The Use of Fluorescent Tracers to Study Distribution of Soil-applied Herbicides[1]

C. G. McWhorter and O. B. Wooten[2]

Work conducted in recent years with volatile herbicides has shown that many of these materials give extremely variable results when sprayed on the soil surface but are fairly consistent when incorporated in the soil. Methods of determining distribution and placement of these materials in soil are generally tedious and often complicated due to a number of factors, including volatilization and leaching. Substitution of a fluorescent material for the herbicide in the application equipment offers a useful method of studying placement and distribution of sprays in the soil.

Fluorescent materials have been used extensively to detect spray and dust deposits on plants (7, 8), but comparatively little use has been made of these materials as a means of studying soil-applied materials. Ranney and Hillis (6) used a fluorescent indicator to determine the placement and degree of dispersion of a fungicide following furrow placement. Johnson and Hillis (4) and Garber and Leach (3) used a similar technique and concluded that these materials offered possibilities for rapid evaluation of distribution patterns. Results obtained by Staniland (8) showed the use of fluorescent tracers to be much simplier and less time consuming than earlier techniques for evaluating soil incorporation in which detectable materials such as iron particles were used (5).

Fluorescent materials. The term fluorescence applies to the absorption of radiation of a particular wavelength by a substance and its re-emission as light of longer wavelengths. Generally, ultraviolet radiation is used to produce the visible fluorescence.

Several fluorescent materials have been studied and found suitable for incorporation with spray solutions or dusts. These materials have been categorized by Sharp (7) as (a) strongly fluorescent solids that are not appreciably water-soluble, (b) fluorescent solids that are water-soluble, and (c) non-fluorescent powders that dissolve in water forming strongly fluorescent solutions. Although most workers find it more convenient to use water-soluble materials, many of the insoluble powders are more economical to use. A large number of materials in each of the three categories have been characterized in the literature as to color of fluorescent and solubility (7,8).

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[2]Plant Physiologist, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, and Mississippi Agricultural Experiment Station, Stoneville, Mississippi, and Agricultural Engineer, Agricultural Engineering Research Division, Agricultural Research Service, U. S. Department of Agriculture. The work reported was done in cooperation with the Delta Branch of the Mississippi Agricultural Experiment Station, Stoneville, Mississippi.

Photography and examination of fluorescent deposits. Examination of deposits is accomplished with the aid of an ultraviolet light under dark conditions. While this can be done most easily at night, observations can also be made during the daylight hours in the field if a lightproof cabinet is available. The general light absorption range of the tracer used should be known prior to its application, since several commercially available materials will not fluoresce under long wave ultraviolet (3600–3700 angstroms) radiation. Because of this, it is usually advisable to use a lamp that emits at a shorter wavelength (2500–2600 angstroms). Continued exposure to short wave length ultraviolet is injurious to the eyes. Optical glass will give adequate protection. For a person who does not normally wear glasses, special protective goggles are available. Although visual observations can be made with lamps containing 50–75 watt bulbs, photography of deposits is simplified by use of lamps containing 100–200 watt bulbs, since the exposure time can be reduced. Such lamps generally require 110–volt alternating current. It is convenient if the field work can be conducted within range of an extension cord from a 110–volt outlet, but if this is not possible, 110–volt alternating current can be supplied with a portable generator or a converter. A converter will permit use of 110–volt lamps from a 12–volt direct current source such as an automobile battery. Adapters are available that can be attached to the converter and plugged into an electrical cigarette lighter to simplify connection of the light source to an automobile battery.

Care should be taken in the photographing of fluorescent subjects to exclude ultraviolet light from the camera lens, since ultraviolet light will cause serious fogging of the film. This can be accomplished through use of an ultraviolet-absorbing filter at the camera lens. If color rendition is important, a Wratten 2B filter should be used. If black and white film is used, either a Wratten K2 or 2B filter may be used (1). If some special effect is desired, a large number of filters are available on which light transmittance and spectrophotometric absorption curves have been determined (1,2).

When brilliant spray deposits are to be photographed, any good grade of film can be used. Since most deposits are generally quite weak because of soil dilution, it is best to use a film with a high ASA rating. Black and white film can be obtained with ratings up to ASA 500 and color film with ratings up to ASA 160. Use of films with the higher ratings greatly reduces the required exposure time.

Methods and Materials

The fluorescent tracer used in these studies was zinc ortho silicate compound 2282 from Sylvania Electric Products, Inc., which fluoresces green under ultraviolet light. This material was essentially insoluble in water and was applied with a tractor-mounted plot sprayer. Bypass agitation was sufficient to keep the material in

suspension. Rate of application was 10 lb/A in a broadcast rate of 40 gallons of water-suspension per acre. Various treatments were applied either to the soil surface and incorporated, or were applied underground with the equipment described by Wooten and McWhorter (9). In one experiment in which the material was used to aid in establishing the placement of EPTC (ethyl *N*,*N*–di–*n*–propylthiolcarbamate), the machine setting thought to be most desirable was selected and the fluorescent tracer applied. Without making any changes in the machine setting, EPTC was exchanged for the tracer in the spray system and was applied in the same manner.

Tracer placement was determined by digging a pit within the treated area and carefully cutting away one side of the pit with a sharp-edged instrument so that a smooth profile was developed. Care was taken to ensure that tracer material cut away in the upper portion of the profile did not adhere to the lower portion of the profile surface. In the preparation of the profile, several inches of soil were sheared away to make sure that a representative portion of the treated area was exposed. During profile preparation, examination, and photographing of the deposits, the ultraviolet light was placed in the bottom of the pit, as shown in Figure 1. A fluorescent wire was stretched across the top of the row to differentiate between the above-ground and below-ground portions of the soil recorded in photographs. Photographs were taken with a camera mounted 33 inches from the soil profile. The camera contained color film with an ASA rating of 100. Time exposures were taken at 30, 60, and 180 seconds at f 3.5. Generally, the 30-second exposure provided the best photographs.

Figure 1. A camera and ultraviolet light in position to record the distribution of a fluorescent tracer throughout the soil profile. Note the position of a fluorescent wire across the upper edge of the profile.

RESULTS AND DISCUSSION

The methods of soil incorporation evaluated in this study may be divided into three groups: (a) Sprayed on the soil surface and incorporated with a disk or rotary hoe, (b) sprayed underground with an underground applicator, and (c) sprayed on the soil and then covered with middlebreakers.

One disking treatment applied following surface application of the tracer gave poor subsurface distribution (Figure 2). Most

Figure 2. Distribution of a fluorescent tracer in soil following one disking. The continuous white line across the photograph represents the soil surface of a soil profile. White areas above the line represent tracer on the soil surface while those below the line represent tracer mixed with soil.

of the fluorescent material remained on soil aggregates exposed to the atmosphere, and only the smaller tracer-coated aggregates were covered by the disking. More uniform soil distribution was obtained with each additional disking until three diskings had been applied to a given area (Figure 3). Although it is generally assumed that repeated disking pulverizes soil to a greater extent than a single disking, this did not appear to be true for the conditions under which this work was conducted. Even though better subsurface tracer distribution was obtained with three or more diskings, examination of the deposits did not indicate that the tracer-coated clods produced by the first disking were broken up by successive diskings, i.e., it did not appear that 4, 5, or 6 diskings gave any better tracer distribution than 3 diskings.

Rotary hoeing following surface application gave distribution similar to that obtained with a disk. One rotary hoeing left large tracer-coated clods on the surface and incorporated only small soil particles.

Underground tracer patterns were studied, using five types of nozzle tips mounted on an underground applicator. These tips were

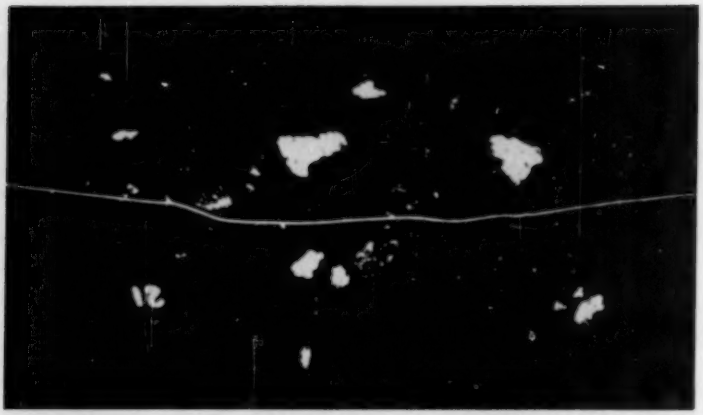

Figure 3. Distribution of a fluorescent tracer in soil following three diskings. The continuous white line across the protograph represents the soil surface of the soil profile. White areas above the line represent tracer on the soil surface while those below the line represent tracer mixed with soil.

a 150°-angle flat fan tip, a flooding-type tip, a square pattern tip, an atomizing-cone tip, and an insecticide hollow-cone tip. The 150°-angle tip sprayed a band of tracer approximately 16–18 inches wide. This distinct band was one-fourth to three-fourths of an inch thick (Figure 4). All other nozzle tips gave much narrower bands, 8–10 inches wide, that were generally one-half to one inch thick. Use of three narrow angle nozzle tips mounted on the underground

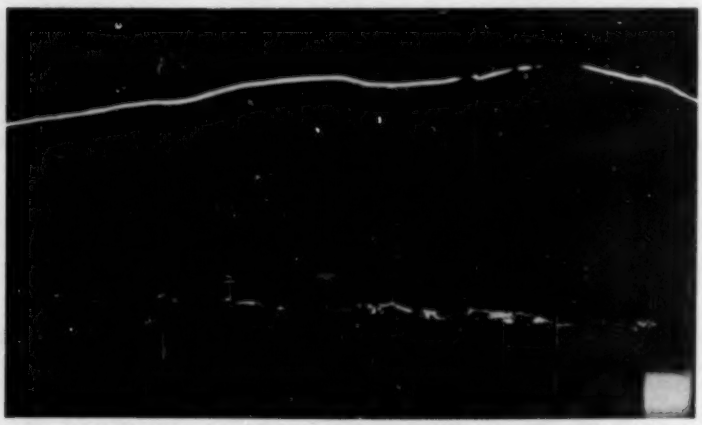

Figure 4. Distribution of a fluorescent tracer in soil following application with an underground sprayer equipped with a 150°-angle nozzle tip.

applicator gave three narrow distinct bands of tracer on the same horizontal plane. This demonstrated that it would be possible to apply an herbicide in underground bands on either side of the crop seed zone so that no chemical would be either above or below germinating crop plants. If such a need should arise, this or many other similar modifications of subsurface chemical application would be easily obtainable with this underground applicator (9).

The method that gave the most even distribution of tracers in the soil was that of applying the material in a subsurface band (as shown in Figure 4) and mixing this with a rotary hoe. The distribution obtained with this technique is shown in Figure 5. The depth and width of this treated area could be varied by regulation of depth of placement of the underground applicator and by variation of the nozzle tip to be used.

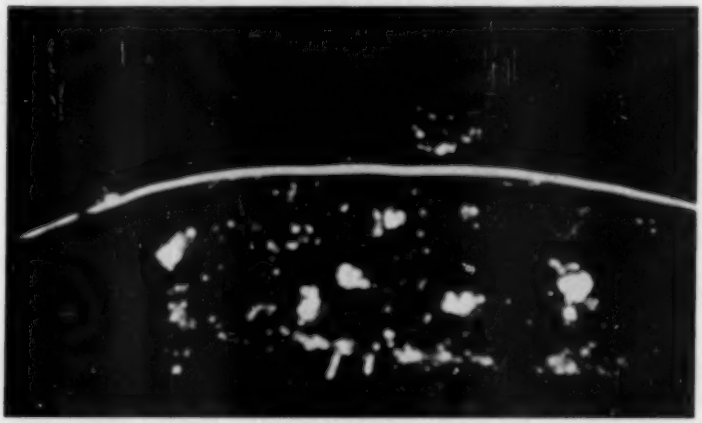

Figure 5. Distribution of a fluorescent tracer in soil following underground application and rotary hoeing. The continuous white line across the photograph represents the ground line of a soil profile. White areas above the line represent tracer on the soil surface while, those below the line represent tracer mixed with soil.

Two placement methods were evaluated, using row bedding equipment. These methods were studied because it was felt that herbicide application at bedding time would eliminate an additional operation. Patterns obtained by spraying the material on the ground and immediately bedding soil over it are shown in Figure 6. The chemical was covered satisfactorily by this method and, although the patterns obtained in this work were irregular, it is possible that this method of application could be refined and developed to work satisfactorily.

With the exception of the row bedding method, the methods of tracer application discussed in this paper were also used to apply

EPTC. While this work is preliminary, it is evident that the overall efficiency of EPTC was greatly increased by subsurface placement. The data obtained indicated that there was a direct correlation between the activity of EPTC and the degree of soil incorporation (9).

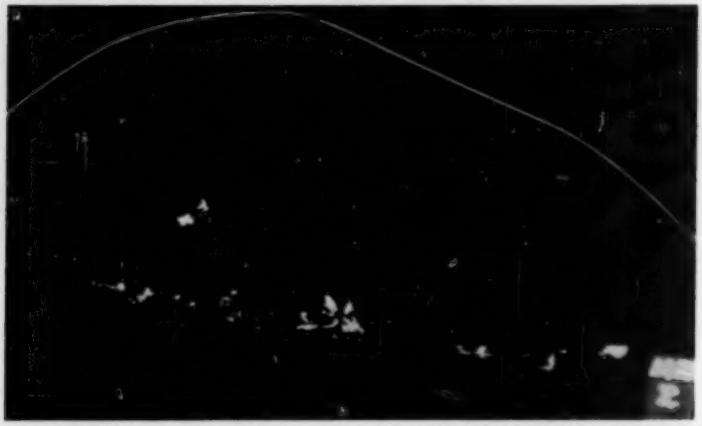

Figure 6. Distribution of a fluorescent tracer that was applied to the soil surface and bedded on with middlebreakers.

SUMMARY

A technique for using a fluorescent tracer for the study of spray deposits in soil is described. This technique was used in evaluation of several methods of soil incorporation that were intended for use in a study on volatile herbicides. Of the soil incorporation methods evaluated, use of a wide angle nozzle tip on an underground applicator, followed or not followed by rotary hoeing, appeared the most promising for effective application of volatile herbicides such as ethyl *N*,*N*–di–*n*–propylthiolcarbamate (EPTC).

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Control of Blackjack Oak by Basal Spraying with 2,4,5–T[1]

FRED A. PEEVY[2]

INTRODUCTION

BASAL stem sprays of an ester of 2,4,5–trichlorophenoxyacetic acid (2,4,5–T) mixed with a light oil such as kerosene or diesel oil have proved to be effective for controlling a number of species of woody plants. In general, the recommendation has been to apply the herbicidal solution in a band around the base of the stems and allow the solution to flow down the bark to the ground (1, 4, 6). However, different band widths have been suggested by workers in various parts of the country (2, 3, 5, 7).

METHODS AND MATERIALS

In April 1955, an experiment was begun at the Alexandria Research Center to obtain information on the effectiveness of 2,4,5–T ester applied in varied band widths at the base of trees for control of blackjack oak *(Quercus marilandica)*. The propylene glycol butyl ether ester of 2,4,5–T was applied in a concentration of 8 lb ahg of diesel oil. Applications were made during April, July, October, and February for two consecutive years. The solution was applied in volumes of 16, 32, and 64 ml per inch of stem diameter to the lower 8, 12, and 16 inches of the tree trunks. Thus, rate of treatment and volume of spray were confounded. Ten trees, 3–10 inches in diameter, were treated for each volume and band width at each date of treatment. Diameter measurements were made 4½ feet above ground level. Treatments were replicated three times. Sixteen pounds of 2,4,5–T per hundred gallons of oil was applied in a 16-inch band as a standard treatment. In order to obtain additional information on the effect of volume, 8 pounds of 2,4,5–T per hundred gallons of oil was applied at the rate of 48 ml per inch of stem diameter in a 12-inch band during the last four dates (Figure 1).

Figure 1. Applying 2,4,5–T as a basal spray to lower 12 inches of a blackjack oak.

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[2]Range Conservationist, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, cooperating with the Southern Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Alexandria, Louisiana.

RESULTS AND DISCUSSION

The percentage of trees killed was recorded three growing seasons after treatment. The application of 2,4,5–T ester at 8 lb ahg of diesel oil and 16 ml per inch of trunk diameter was relatively ineffective at all three band widths (Table 1). When the herbicidal solution was applied in a volume of 32 ml per inch of trunk diameter, 51 percent of trees were killed when the solution was applied in an 8-inch band. A slightly lower percentage of trees were killed when the solution was applied in wider bands.

Table 1. Effects of solutions of 8 pounds of 2,4,5–T per hundred gallons of diesel oil, sprayed on bands of various widths, applied from April 1955 to February 1957, on killing of blackjack oak, as shown by data recorded three growing seasons after treatment.

Solution per inch of trunk diameter and month of treatment	Average percent kill							
	8-inch band		12-inch band		16-inch band		Average all bands	
	Top	Root	Top	Root	Top	Root	Top	Root
16 ml								
April	50	38	38	32	40	22	43	31
July	30	17	40	13	23	15	31	15
October	37	30	35	23	27	27	33	27
February	68	52	63	55	58	35	63	47
Average	46	34	44	31	37	25	42	30
32 ml								
April	70	58	80	62	78	45	76	55
July	62	50	58	40	58	32	59	41
October	58	53	52	48	40	27	50	43
February	88	70	82	63	72	63	81	65
Average	70	58	68	53	62	42	67	51
64 ml								
April	92	82	98	92	98	78	96	84
July	93	80	90	63	98	83	94	75
October	95	85	77	67	73	60	82	71
February	100	90	97	85	100	78	99	84
Average	95	84	91	77	92	75	93	79
32 ml 16 lb ahg								
April					83	59		
July					65	52		
October					72	57		
February					88	73		
Average					77	60		

Sixty-four ml of solution per inch of trunk diameter was more effective than lower volumes. Seventy-nine percent of the trees treated with the higher volume rate of herbicide in oil solution were killed. An average of data for the three band widths shows that good kills were obtained. For all treatment dates, 84, 77, and 75 percent of the trees were killed for the 8-, 12-, and 16-inch band widths, respectively. An analysis of variance showed no significant differences in kill among widths of bands from applying 16 ml or 64 ml of solution per inch of diameter, but the differences in kill were significant when the solution was applied in a volume of 32 ml per inch.

The best kills were obtained from applications made in February when the solution was applied at 16 ml per inch of diameter. However, these results were unsatisfactory since the best kill was only slightly above 50 percent of trees. When the herbicidal solution was applied in a volume of 32 ml per inch of trunk diameter, a higher percentage of trees was killed by treatments applied in February and April than for treatments applied in July and October. The highest percentage of trees was killed by applying the solution in an 8-inch band in February. The percentage of trees killed was about the same when the solution was applied to either an 8-inch or a 12-inch band during April. Good kills of trees were obtained for each of the four treatment dates when the solution was applied at 64 ml per inch of diameter in an 8-inch band. Better kills were obtained for treatments applied in February and April than in July and October for applications made in a 12-inch band. In general, the results were good when the solution was applied at this volume to a 16-inch band. The lowest percentage of tree kill was obtained for October treatments.

The differences in kill among treatment dates were significant when either 16 ml or 32 ml of solution were applied per inch of trunk diameter, but there were no significant differences when the solution was applied at 64 ml per inch.

The standard solution, 16 pounds of 2,4,5–T ester per hundred gallons of oil applied in a 16-inch band in a volume of 32 ml per inch of trunk diameter, was less effective than a solution containing 8 lb ahg of oil applied at 64 ml per inch in a 16-inch band. This suggests that the more dilute solutions at higher rates may be the most effective method of applying a given amount of herbicide. The rate of herbicide was the same.

The application of 8 pounds of 2,4,5–T ester per hundred gallons of oil in a volume of 48 ml per inch of diameter in a 12-inch band at base of trees for the last four treatment dates was as effective as application in a volume of 64 ml per inch in a similar band, except that the July application at the higher rate effected the best top-kill. However, the percentage of trees killed was the same for both treatments for this date of application. These results indicate that a volume greater than 32 ml per inch of trunk diameter is needed but that the least volume required for effective activity may be less than 64 ml. Further research is needed to determine the critical volume.

SUMMARY

Eight pounds ahg of the propylene glycol butyl ether ester of 2,4,5–T in 100 gal. of diesel oil was applied as a basal stem spray in three volumes to each of three band widths during April, July, October, and February from April 1955 to February 1957. Sixteen pounds of 2,4,5–T ester per 100 gal of oil was applied at the rate of 32 ml per inch of stem diameter as a standard treatment.

The 2,4,5–T ester in a concentration of 8 pounds per hundred gallons of oil at 16 ml per inch of trunk diameter was relatively

ineffective, but fair kills were obtained when the same solution was applied at a volume of 32 ml per inch of trunk diameter. The best kills were obtained when the volume was increased to 64 ml per inch. Application of the solution in this volume gave satisfactory kill regardless of band width. There was a slight trend favoring a concentration of all the spray in an 8-inch band, as compared with the 12- and 16-inch bands, for each of the three volumes tested.

The best results were obtained from February treatments, and the second best when applied in April, with poorer results in July and October. With sufficient rates good results were obtained at all dates of treatment.

The standard solution of 16 pounds of 2,4,5–T ester per hundred gallons of oil applied in a 16-inch band at 32 ml per inch of trunk diameter, was less effective than 8 pounds of 2,4,5–T per hundred gallons of oil applied at 64 ml per inch in a similar band. Eight pounds of 2,4,5–T ester per hundred gallons of oil at 48 ml per inch of diameter in a 12-inch band at the last four dates was about as effective as when applied at 64 ml per inch in a similar band.

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The Role of Surfactants in the Foliar Absorption of Indole-3-Acetic Acid (IAA)[1]

R. E. Hughes and V. H. Freed[2]

The absorption of chemicals by the leaf of a plant is a problem of major importance in chemical weed control. The presence of a waxy cuticle on the surface presents a barrier to absorption. Interspersed in the cuticle are the stomata which may serve as a portal of entry for chemicals but even the interior chambers of the stoma are lined with a cuticle. It may be presumed that the more intimate the contact between a chemical and the leaf surface the greater the possibility for absorption. The water carrier commonly used in application of these chemicals makes but a poor contact with the cuticle; however, this deficiency may be overcome by the addition of agents to lower the surface tension of the solution. While intimacy of contact of the chemical with the leaf surface is important in absorption, the state, i.e. liquid or solid, of the chemical may also influence the ease of absorption. Consideration of the physical processes involved shows that a chemical will be absorbed with relative ease from a liquid phase in contrast to the same chemical deposited as a crystal on the surface of the leaf. Either humid conditions following application or the addition of hygroscopic agents may help to maintain a liquid state thus facilitating absorption. Many surface active agents used in sprays are also fair hygroscopic agents.

Currier[3] reports that absorption occurs through both the stomata and cuticle. He maintains that cuticular absorption is slower than stomatal and continues only as long as the spray deposit remains fluid. He further reports that surfactants are more effective in stomatal than cuticular absorption. However, the study reported by Volk and McAuliffe (12) suggests that an appreciable amount of urea may be absorbed through the cuticle. These authors found that reducing the barrier afforded by the cuticle by abrasion markedly increased the amount of chemical absorbed. Similarly, in working with tobacco leaves, they found no difference in the absorption between the top and bottom surfaces of the leaf. They also demonstrated that the absorption of urea by tobacco plants was greater at night than during the day. This finding suggests that the absorption was primarily through the cuticle since ordinarily the stomata of the plant are open by day but closed at night. However, this observed effect may have been due to the higher humidity at night. Horie (9) found radish plants absorbed the same amount of urea either in light or dark, but tomato plants were found to absorb more in the dark.

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[2]Department of Agricultural Chemistry, Oregon State College, Corvallis.

[3]Currier, H. B., California Agr. Exp. Sta., Ann. Report of Cooperative Regional Project W-11, Penetration of Herbicides. December 8, 1958.

Some of the factors influencing the absorption of chemicals by plant foliage have been elucidated by Smith et al. (11) in their work with maleic hydrazide. These authors found that humidity, type of formulation and the relative water condition of the plant had the greatest effect on foliar absorption while plant species, rate of application, temperature and light had only small to moderate effects. Humidity was found to be a particularly critical factor in that there was a direct relationship between humidity and amount of chemical absorbed in a given length of time. Smith et al. (11) report that the rate of absorption appears to follow first order rate law and that the time required for one-half the chemical to be absorbed decreases by 15% when the chemical is applied as a film rather than as a drop. This concept is supported by the work of Barrier and Loomis (1) who found that absorption increased with increasing rate of application or increasing surface concentration. These authors also found that temperature had a marked effect on the absorption by bean plants.

The role of surfactants in foliar absorption of chemicals was studied by Dorschner and Buchholtz (4) who found that increased wetting, that is, lowered surface tension, gave a two to four-fold increase in absorption. Brown (3) and Harley et al. (8) report that the use of wetting agent with defoliants increased the amount and rapidity of defoliation. This finding indicates that the surfactant increased the rate of penetration of the chemical. The work of Hauser (10) on the absorption of 2,4–D also indicates that the addition of surfactants increase absorption. However, in this instance there was a loss of differential selectivity upon addition of a surfactant. He likewise found that the rate of absorption correlates with the exposure period and increased as the concentration of chemical per unit volume increased.

The importance of maintaining the chemical in a fluid film to increase absorption is demonstrated by the work of Gray (6). This author found that glycerine increased the absorption of streptomycin by as much as twenty-four-fold in 96 hours. The glycerin, being hygroscopic, tends to retain a film of moisture on the leaf.

While the lowering of surface tension is important in promoting absorption, this is not the whole story. Freed and Montgomery (5) using several surfactants with amitrole found that the type of surfactant may be as important as its ability to reduce the surface tension of the solution. This interaction between the surfactant and herbicide may be of equal or greater importance than the lowering of surface tension.

With these factors in mind, a study was undertaken to develop a better understanding of the role of surfactants in foliar absorption.

METHODS

Indoleacetic acid (IAA) was the active substance used to study the role of surfactants in foliar absorption. This chemical was chosen because it had been shown by Hamence (7) that it could be deter-

mined in very small amounts by its characteristic fluorescence. Moreover, it is a compound of sufficient solubility that it can be removed from the leaves by means of a dilute basic wash. The chemical was determined by means of an Aminco Bowman spectrophotofluorometer. It was found that there was a linear relationship of concentration with fluorescent intensity over the range of 5×10^{-3} to 2 ppm of IAA.

Bean (*Phaseolus vulgaris*) plants (var. Black Valentine) were planted in pots in greenhouse soil and grown to full development of the first primary leaf. At that time from 30 to 50 µl of IAA solution containing 1,000 ppm chemical was applied to the primary leaf. Application, which was made with a microsyringe, was confined to an area 12 mm in diameter. In order to confine the application to such an area, a lanolin ring of this diameter was impressed upon the leaf. One such application was made on each leaf. All surfactants used in this study were at a concentration of 0.1% active ingredient. At various time intervals, the treated leaves were harvested and the IAA washed from the leaf with 1×10^{-4} M NaOH. At least four leaves per sample were used. The leaf washings were diluted in a volumetric flask to give a concentration that could readily be determined by the fluorescent intensity measurement.

In this report, it is assumed that the difference between the amount of chemical applied and the amount of chemical washed off at various time intervals represents the amount of chemical absorbed by the plant.

Results and Discussion

The first experiment was a comparison of the effectiveness of a number of surfactants in increasing absorption of IAA. In this study the surfactant was added to an IAA solution at the rate of 0.1% of active ingredient and applied to the leaf. Samples were taken at two, four, and six days following the application and the amount of chemical absorbed at each time interval measured. These data, together with the surface tension of the solution, are presented in Table 1. An average of six or more separate determinations are represented in each figure.

The data presented in Table 1 immediately reveal the value of a surfactant to promote absorption. In all comparisons, more chemical is absorbed with a surfactant than when none is present.

Table 1. Average percentage of IAA absorbed by bean leaves.

Treatment	Surface tension dynes cm^{-1}	Pct. IAA absorbed in		
		2 days	4 days	6 days
1. IAA	69.2	27	36	40
2. IAA + 0.1% polyoxyethylene sorbitan monolaurate	41.8	56	80	88
3. IAA + 0.1% isooctyl phenoxy polyethoxy ethanol	34.8	63	76	80
4. IAA + 0.1% alkyl aryl polyoxyethylene glycol	41.8	37	47	
5. IAA + 0.1% sodium dioctyl sulfosuccinate	33.5	45	66	77
6. IAA + 0.1% lauroyl sarcosine	26.4	55	76	85
7. IAA as calcium salt			9	17

It may also be seen from this table that there are substantial differences among surfactants in the promotion of the absorption of IAA. It will be noted, in comparing the amount of chemical absorbed to the surface tension of the solutions, that surface tension alone is not a sufficient and necessary criterion to determine absorption. The surfactant giving a surface tension of approximately 42 dynes per cm resulted in equally good absorption as the one reducing the surface tension to 26 dynes per cm. Thus, once again the subtle interaction of surfactant with the species of molecule to be absorbed is demonstrated.

In the course of this investigation, a marked variation in absorption was noted from one run to another. The variations were ascertained to be correlated, at least in part, with variations in greenhouse conditions from one period to the next. The fluctuation of greenhouse temperature and humidities observed during the course of these studies was a range of 63 to 74° F in temperature and 40 to 70% relative humidity. In an attempt to determine the influence of a surfactant under varying conditions, six separate runs were made to compare IAA alone and IAA plus a surfactant with respect to the amount of chemical absorbed. These data are presented in Table 2.

Statistical analysis of the data in Table 2 reveals that the variation in absorption caused by varying environmental conditions is markedly reduced by the addition of a surfactant. It would seem, therefore, that one of the benefits derived from the use of surfactants is to reduce the variability in absorption and insure more uniform action despite the changes in climatic conditions.

The data presented in Table 2 indicate that absorption of IAA is following a first order rate law. In the case of IAA alone, a constant (k) of 0.17 days^{-1} was found, whereas, with a surfactant a constant of 0.386 days^{-1} was obtained. This demonstrates once again that the surfactant is promoting absorption of IAA.

A study of Table 2 shows that there is a short period during which the chemical is rapidly absorbed, followed by a gradual

Table 2. The influence of surfactant on absorption of IAA.

	IAA + surfactant[a]			IAA alone		
	Pct IAA absorbed in					
	2 days	4 days	6 days	2 days	4 days	6 days
Six separate runs of each period	80	92	96	48	55	48
	55	83	92	31	40	42
	46	74	81	10	30	48
	55	87	96	16	29	40
	43	60	73	33	35	33
	58	84	88	22	26	31
Average	56.2	79.5	87.7	26.7	35.8	40.3
Std. dev. ±	13.1	11.1	9.2	13.6	10.6	7.2
Coef. of variation	22.3	14.0	10.5	51.0	29.6	17.8

LSD .05 = 6.0.
[a]0.1%. Polyoxyethylene sorbitan monolaurate.

lessening of the absorption rate until, after about the fourth to sixth day, the rate of absorption is markedly diminished. Table 2 reveals that not only does the surfactant increase the total amount of chemical absorbed, but it also increases the speed of absorption during the initial period. It would seem that under adverse climatic conditions, the promotion of rapid absorption would be highly desirable in obtaining satisfactory results with herbicides.

From the foregoing, it appears that at least two functions may be ascribed to the surfactant in promoting absorption. The first of these functions is to increase contact with the leaf surface and the second is to maintain the spray deposit in a fluid condition. It may be readily demonstrated that the energy required for absorption of a chemical from a fluid state is much less than that required for absorption from the crystalline state. The hygroscopic surfactants would tend to hold water at the surface of the leaf, maintaining a fluid state which would tend to minimize the effect of humidity changes on absorption. Such an explanation is consonant with the finding of the decrease in variability of absorption in the presence of a surfactant.

SUMMARY AND CONCLUSIONS

The following inferences may be drawn from the data presented in this study:

1. The foliar absorption pattern of IAA follows an initial phase of rapid absorption, declining markedly in rate from the fourth through the sixth day.
2. All surfactants increase both rate of absorption and the total amount of chemical absorbed.
3. There is an interaction between the surfactant and the species of chemical being absorbed which involves not only the ability of the surfactant to reduce surface tension, but also the chemical nature of this agent.
4. The presence of a surfactant markedly reduces the variation in absorption induced by climatic conditions. It is felt that this factor may be important in field applications of herbicides in that the use of the surfactants may reduce the variation in results obtained under adverse conditions.
5. It has been shown in this study that foliar absorption of IAA follows a first order rate law.

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Recent Advances in the Chemical Control of Wild Oats[1]

G. W. SELLECK[2]

THE wild oat developed along with man's early agricultural activities, adapted to his artificial environments and accompanied him in his migration, to become a major problem in grain growing areas of Europe, Asia, Australia and North America. Manson's survey (17) revealed approximately 61 million acres of cultivated land infested with wild oats in western Canada. At the present time, the weed infests most soils in the black and transition black-grey soil zones and medium- to fine-textured soils in the dark brown soil zone. In the brown soil zone, wild oats are usually confined to fine-textured soils or to depressional areas. "Moderate" infestations reduced barley yields by 15.5 percent and flax yields by 79.4 percent during a four-year period.[3] Severe infestations may occasionally produce as many as 900 to 1,000 plants per sq m, in which case they are "turned under" since competition from such an infestation makes crop production impractical.

Wild oats have been controlled by cultural means in western Canada (16), but adverse weather conditions, measures for control of soil erosion, moisture conservation, or insect control frequently disrupt the weed control program. The major survival mechanisms of wild oats are dormancy, which precludes exhaustion of the seed supply by germination in any one year, and longevity, which permits the seed to live for long periods (5) under conditions which are unfavorable for germination. As a result of genetic divergence, seeds collected from various locations do not germinate uniformly when placed in the same environment (15). Because of these problems, several workers are studying the nature of dormancy of the wild oat (3, 10, 11).

From 1951 to 1955, 13 chemicals were field-tested in western Canada as possible selective herbicides for wild oat control. In 1956, the pre-emergence herbicides isopropyl *N*–phenylcarbamate (IPC) and isopropyl *N*–(3-chlorophenyl)carbamate (CIPC) were released to growers in western Canada for the control of wild oats in certain specialized crops (2). Since 1955, only maleic hydrazide (MH) and 2,2 dichloropropionic acid (dalapon) of this group have been evaluated further. These herbicides prevent normal development of wild oat seed, but it is difficult to accomplish this without injuring the crop (1, 4).

During the period 1956–1959, an average of 26 chemicals have been field-tested annually for wild oat control in western Canada.

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[2]Assistant Professor of Plant Ecology, University of Saskatchewan, Saskatoon, Canada.

[3]Kirk, L. E., and Pavlychenko, T. K. Unpublished report. Report of Investigations at the Research Laboratory of Plant Ecology, University of Saskatchewan, Saskatoon. pp. 25–37. 1938.

It is the purpose of this paper to discuss the more important herbicides tested for wild oat control, with emphasis on work done at the University of Saskatchewan since 1955.

PROCEDURE

Herbicides for wild oat control were applied to natural wild oat infestations on silty clay loam soil in the Saskatoon and Naicam districts and on loam soil near Spalding, Saskatchewan. Seeded infestations were also treated at Saskatoon. Herbicides were applied with a 4-ft push-type sprayer to quadruplicated small plots (4 by 18 ft). Duplicated, medium-sized plots (15 by 135 ft) were treated with granular herbicides (applied with a Gandy spreader) and liquid herbicides (applied with a Chesterford logarithmic sprayer). A farm sprayer was used for applications on large plots (one-half to one acre in size) without replication. A treated plot was located adjacent to a check plot on one or both sides. A harrow or a disk implement was used to incorporate herbicides into the soil after spraying. The majority of the trials involved testing 1,2,4,5–tetrachlorobenzene,[4] 2–chloro–*N*,*N*–diallylacetamide (CDAA)[5], barban[6] (4–chloro–2–butynyl *N*–(3–chlorophenylcarbamate), EPTC[7] (ethyl *N*,*N*–di–*n*–propylthiolcarbamate), simazine[8] (2–chloro–4,6–bis(ethylamino)–*s*–triazine), and 2,3–dichloroallyl diisopropylthiocarbamate[5] (hereafter referred to as 2,3–DCDT), in various crops. Percent control was based on visual estimates and checked by quadrat counts. To supplement field tests, 2,3–DCDT, was applied to wild oat-infested soil and barban to wild oats in the greenhouse, each at rates of 0.75 and 1.5 lb/A.

RESULTS

CDAA.

In 1956, at Saskatoon, CDAA at 3, 6, and 12 lb/A was incorporated into the soil with a double-disk and the plots were seeded to Norland flax, Argentine rapeseed, green foxtail and wild oats on silty clay loam soil. The 12 lb rate provided satisfactory control of wild oats without adversely affecting yields of flax or rapeseed.

In 1957 at Spalding, one-acre plots were treated with CDAA spray and granular materials at rates which ranged between 2 and 4 lb/A. Control was inadequate with spray but was satisfactory with 4 lb/A of granular material (Table 1). In a single experiment, conducted at Saskatoon on silty clay loam soil, the 3 lb and 4 lb/A rates reduced wild oats by 50 percent. Little reduction of wild oats was obtained at lower rates.

During 1958 at Spalding, where a logarithmic sprayer was used, only 50 percent control of wild oats was obtained at 11.5 lb/A and

[4]Supplied by the Dow Chemical Company.
[5]Supplied by the Monsanto Chemical Company.
[6]Supplied by the Spencer Chemical Company.
[7]Supplied by the Stauffer Chemical Company.
[8]Supplied by the Fisons Chemical Company.

Table 1. The effect of CDAA on wild oats in barley at Spalding, 1957.

CDAA	Rate lb/A	Soil incorporation	Mean no. of wild oats per 0.5 sq m		Percent control
			Treatment	Check	
Granular	4	Harrow	9	30	70
Granular	4	Nil	28	153	82
Granular	3	Harrow	36	79	54
Granular	3	Nil	289	350	17
Granular	2	Harrow	49	79	38
Granular	2	Nil	150	333	55
Spray	4	One disking	104	201	48
Spray	4	Two diskings	104	214	41
Spray	3	Two diskings	39	37	−5
Spray	3	One disking	47	50	6
Spray	2	Two diskings	37	38	3
Spray	2	One disking	115	139	11

barley was not damaged at 16 lb/A. When granular CDAA at 4 lb/A was applied through a fertilizer attachment in soil adjacent to barley seed, 75 percent of the barley failed to germinate.

Tetrachlorobenzene.

1,2,4,5–tetrachlorobenzene (M757) was tested on wild oats in 1957 on loam and silty clay loam soils, and incorporated into the soil immediately after application. Montcalm barley and Argentine rapeseed were sown three days later. A 10 lb/A rate controlled 48 percent of the wild oats, had no adverse effect on barley, and delayed rapeseed development by two or three days. A greater toxic effect was exhibited when incorporation consisted of two one-way diskings instead of one. Experiments conducted the following year provided similar results. Applications were made in the fall of 1957 and in the spring of 1958 on loam soil at various rates with a Gandy spreader. Fall treated plots were sown to wheat the following spring and spring treated plots were sown to barley four days after application. Spring applications at rates of 14 and 18 lb/A controlled wild oats 75 percent with approximately 50 percent reduction in the stand of barley (Table 2). Applications in the fall were not significantly more effective in controlling wild oats or in increasing the selectivity of the material.

The herbicide failed to control wild oats during the crop year when applied to summerfallow the previous spring. It was applied at rates from 7 to 20 lb/A and was one-wayed into the soil immediately after application. The field was tilled during the summerfallow year as weed growth warranted. In a field of Thatcher wheat the following year (1959), the boundaries of treated and check plots were not discernible either by wild oat control or damage to wheat. In general, the rather unsatisfactory results reported with this herbicide are corroborated by results from other locations in western Canada during 1958 (13).

EPTC.

During 1958, EPTC which was applied with a logarithmic sprayer in tests for wild oat control, gave 95 percent control at 1 lb/A, and

Table 2. Percent control of wild oats with tetrachlorobenzoic acid in wheat and barley at Saskatoon, 1957.

Rate lb/A	Percent control				
	Disked twice			Disked once	
	Wheat	Barley	Wild oats	Wheat	Wild oats
	Fall application				
8	13	–	50	12	25
12	7	–	30	10	60
14	55	–	67	52	40
16	78	–	92	60	55
21	78	–	95	65	57
24	65	–	57	35	25
	Spring application				
7	–	7	40	–	–
10	–	0	30	–	–
12	–	55	60	–	–
14	–	40	75	–	–
18	–	60	75	–	–
24	–	75	90	–	–

6 lb/A merely delayed the development of rapeseed by 2 to 3 days. The applications were made May 9 on silty clay loam soil at Saskatoon and incorporated immediately with a double-disk. Argentine rapeseed was seeded the following day. Similar applications of granular EPTC to barley provided similar wild oat control at a rate of 1 lb/A and decreased the stand of barley by 10 percent. However, the crop yield was increased by at least 10 percent. Heavier rates improved wild oat control and increased crop damage, resulting in a 70 percent stand reduction of barley at 3 lb/A. The liquid formulation which was applied at the same location required a slightly higher rate of application for equivalent wild oat control, but was less harmful to the barley. The 1.6 lb/A rate provided 95 percent control of wild oats, and barley damage was not visible at rates lower than 3 lb/A.

Fall applications of EPTC applied with a logarithmic sprayer and double-disked into the soil, provided 95 percent control of wild oats at 1.1 lb/A on silty clay loam soil, but 4.9 lb was necessary when the herbicide was not incorporated (Table 3). Without incorporation, stand reduction was not evident in Montcalm barley, Norland flax, Argentine rapeseed and Thatcher wheat. With incorporation, crop stands were substantially reduced.

More favorable results were obtained in the spring of 1959, at Spalding. The herbicides were applied May 13 on stubble land at rates which varied from 0.4 lb to 6 lb/A in 16 gal of water. Montcalm barley, Norland flax, Argentine rape and Thatcher wheat were sown the following day. Wild oats were controlled 90 percent at rates from 1.5 lb/A to 20 lb/A. Flax and rapeseed exhibited considerable tolerance, but barley and wheat were damaged at rates necessary for adequate wild oat control (Table 4). In 18 trials with EPTC in western Canada in 1959, wild oats could be controlled, wheat and barley had little or no tolerance, and flax had slight tolerance (14).

Table 3. Percent control[a] of wild oats and percent reduction of crop plants with EPTC October, 1959. The herbicide was applied with a logarithmic sprayer.

Plant	Percent control							
	Disked in				Not disked in			
Wild oats	2.0 / 100	1.1 / 95	0.8 / 90	0.2 / 75	4.9 / 95	3.5 / 90	2.0 / 75	
Montcalm barley	3.8 / 95	2.3 / 90	1.9 / 75		8.0 / 0			
Norland flax	3.7 / 98	1.2 / 90			8.0 / 0			
Argentine rape	1.8 / 95	0.8 / 90	0.2 / 75		8.0 / 0			
Fortune oats	2.3 / 98	1.3 / 95	0.5 / 90	0.3 / 75	3.5 / 95	2.9 / 90	1.6 / 75	
Selkirk wheat	3.3 / 98	1.7 / 95	1.0 / 90	0.5 / 75	8.0 / 0			

[a]The numerator of the fraction represents the rate of application (lb/A) and the denominator the resulting percent control.

Table 4. The percent control[a] of wild oats and percent reduction of crop plants by spring applications of EPTC at Spalding, 1959. The herbicide was applied with a logarithmic sprayer.

Plant	Percent control							
	One disking				Two diskings			
Wild oats	2.9 / 95	1.5 / 90	1.3 / 75		2.7 / 95	2.3 / 90	1.6 / 75	
Barley	4.4 / 50	3.8 / 25			4.6 / 75	3.2 / 50	2.8 / 75	
Flax	6.0 / 0				6.0 / 0			
Rape	6.0 / 0				4.1 / 95	2.4 / 50	1.0 / 25	
Wheat	4.4 / 75	3.0 / 50	1.8 / 25		3.6 / 95	3.3 / 80	2.3 / 40	

[a]The numerator of the fraction represents the rate of application (lb/A) and the denominator the resulting percent control.

Simazine.

Somewhat similar results were obtained in trials with simazine in barley and rapeseed. In 1958, simazine spray at 2.2 lb/A controlled wild oats 95 percent on loam soil, but decreased the stand of Montcalm barley by 85 percent. The weed was controlled only 50 percent by a 4 lb/A rate of the granular formulation. In Argentine

rape on silty clay loam soil, simazine controlled wild oats 100 percent at 2.9 lb/A and 95 percent at 1.3 lb/A. Rapeseed stands were considerably reduced, with the 1.3 lb/A rate decreasing the stand by 30 percent. In each case the herbicide was incorporated into the soil immediately after application. Rapeseed was seeded the following day and barley was seeded after an interval of four days. Other tests in western Canada during 1959 revealed that all crops except corn were damaged at the 1 lb/A rate (14).

2,3–DCDT.

In 1958, 2,3–DCDT (which was applied with a logarithmic sprayer) controlled wild oats 99 percent at a rate of 1.6 lb/A (Figure 1) and barley was decreased in stand by 20 percent at 3.5 lb/A. The herbicide was incorporated immediately with a double-disk and the plots sown to Montcalm barley three days later.

Figure 1. Wild oat control in barley with 2,3–DCDT (left). The herbicide was applied with a logarithmic sprayer at rates which varied between 0.5 and 16 lb/A.

During the spring of 1959, 2,3–DCDT at rates ranging from 0.8 to 3 lb/A were applied to natural infestations of wild oats in Montcalm barley on two soil textures (loam and silty clay loam) and in Norland flax on silty clay loam. Barley was seeded in loam and silty clay loam soils one day and three weeks after spraying, respectively, and the flax was seeded four days after spraying. The 1.5 lb/A rate consistently controlled wild oats (Table 5), particularly when the herbicide was incorporated into the soil with two one-way diskings. Where yields were taken on barley at Spalding, check plots yielded 3 to 4 bu/A while the treated plots yielded 30 to 40 bu/A. Some of the check plots supported more than 1,000 wild oat

plants/sq m. No damage was visible either to barley or flax at the 3 lb/A rate. The increased yield in barley was due to the development of longer and fuller heads in the weed free crop (Figure 2). Soil conditions at the time of seeding were dry at Saskatoon and at Spalding and moist at Naicam. Only 3.5 inches of rain fell during the growing season at Saskatoon and 7.5 inches at the other two locations.

Table 5. The percent control of wild oats in barley and flax with 2,3–DCDT under various conditions at three locations, 1959.

Rate lb/A	Hannchen barley on smf[a] at Saskatoon		Montcalm barley on stubble at Spalding		Norland flax on smf[a] at Naicam	
	Two diskings	One disking	Two diskings	One disking	Two diskings	One disking
0.8	90	75	–	–	–	–
1.0	–	–	60	30	75	50
1.2	95	75	–	–	–	–
1.5	95	90	95	40	98	95
2.0	95	90	95	50	98	98
2.5	95	90	95	50	98	98
3.0	–	–	99	95	98	98

[a]Summerfallow.

Figure 2. Spike development of barley from plots treated with 1.5 lb/A (left) and untreated plot (right). Wild oat infestations in check plots reached 1,000 culms per sq m.

2,3–DCDT was applied with a logarithmic sprayer to 16 additional plots at rates between 0.5 and 6 lb/A at Spalding and seeded to Thatcher wheat, Garry oats, Montcalm barley, Norland flax and Argentine rapeseed. Results followed a similar pattern since wild oats were adequately controlled at approximately 1.5 lb/A (Table 6). Granular applications were only about one-half as effective as the liquid. Solventless 2,3–DCDT (the same herbicide with the solvent lacking) provided excellent control at approximately 0.5 lb/A. Two diskings for incorporation of the herbicide improved wild oat control, particularly on stubble, and appeared to increase the range of tolerance for seeded crops. Barley, flax and rape were not injured at 6 lb/A. 2 lb/A appeared to be the maximum that Thatcher wheat would tolerate without damage.

Table 6. The percent control[a] of wild oats and percent reduction of crop plants with 2,3–DCDT at Spalding, 1959. The herbicide was applied with a logarithmic sprayer.

Plant	Percent control	
	One disking	Two diskings
Wild oats	2.8 / 98 — 1.7 / 95 — 1.6 / 90 — 1.5 / 75	2.2 / 98 — 1.3 / 95 — 0.7 / 85 — 0.6 / 75
Barley	4.0 / 25	6.0 / 0
Flax	4.0 / 25	6.0 / 0
Rape	4.2 / delayed 2 days	6.0 / 0
Wheat	4.0 / 75 — 3.8 / 50 — 2.5 / 25	3.7 / 80 — 3.1 / 50 — 2.3 / 25

[a]The numerator of the fraction represents the rate of application (lb/A) and the denominator the resulting percent control.

2,3–DCDT was applied with a farm sprayer to four acres of summerfallow at 1.5 lb/A in 4.5 gal of water, May 15, 1959. The field was cultivated, harrowed, sprayed, harrowed and seeded to Thatcher wheat in that order, in a single day. Wild oats were controlled 99 percent and the undamaged wheat yielded 40 bu/A. The grain was somewhat stunted and the heads were shorter, however, in crescent-shaped patches on the turns where overlapping of swathes occurred.

In greenhouse trials, 2,3–DCDT controlled wild oats 100 percent at 1.5 lb/A and 90 percent at 0.75 lb/A, without harmful effects to flax. The wild oats emerged, reached a height of 1 to 2 inches and remained at this stage for a period of three weeks. At the end of this time, the leaves dried up and the seedlings died. Inspection of the seedlings revealed swollen crowns and a lack of crown root development. On most of the plants which were treated at 0.75 lb/A and survived, the centre of development, resembling a crown, was located inside the empty hull of the caryopsis. A few of the survivors were developing normally.

Barban.

The post-emergence herbicide, barban, was applied with a logarithmic sprayer at a maximum rate of 6 lb/A to wild oats in Thatcher wheat and Montcalm barley in 1958. The wild oats and crops (situated on silty clay loam soil) were treated in the 4-leaf and boot stages. The wild oats which were treated in the 4-leaf stage remained dormant until plants in check plots were headed. At this time (early July) three inches of rain fell and the treated wild oats resumed their development, producing mature seed. Barley and wheat were stunted and delayed at rates in excess of 2.6 lb/A.

The herbicide was less effective on wild oats when applied in the boot stage. Friesen (7) and Sexsmith (18) obtained fair to good control with barban at ½ lb/A with applications prior to the 3-leaf stage. Most other workers obtained good wild oat control at 1 lb/A (14).

During 1959, barban at a rate of 1.2 lb/A gave 90 to 95 percent control of wild oats in six of nine plots which were sprayed in the 1¾ to 2 leaf stage (Table 7). Satisfactory control was obtained also in two plots which were treated when wild oats were in the 3-leaf stage. Barban was applied at a maximum rate of 2 lb/A with a logarithmic sprayer in volumes of 15 and 30 gal of water/A in 28 plots on silty clay loam soil. The wild oat infestation was a natural one on stubble land and was seeded to Selkirk wheat, Garry oats, Montcalm barley, Norland flax and Argentine rapeseed. The soil was very dry at the time of seeding (May 1) resulting in uneven germination. The wild oats had an additional advantage, since at the time of seeding, epicotyls were protruding from wild oat caryopses. Dry weather which followed, resulted in poor crop development. Wild oat control was inadequate when the herbicide was applied in the 1½ to 1¾, 2 to 2¾ and 3½ to 4 leaf stages. The results of these treatments were highly inconsistent. One or two plots of each group of four provided 90 to 95 percent control of wild oats at a rate of 1.5 lb/A. With the remaining plots, the 2 lb/A rate was inadequate. The herbicide was applied to barley in the 1 leaf, 1¼ to 1½, 2¾, and 3 leaf stages. Wheat was sprayed at similar stages and flax and rapeseed were sprayed at emergence and at heights of 1 inch and 4 inches. Fortune oats was sprayed in the 2 to 2¾ leaf stages. The oats were comparable to wild oats in suscepti-

Table 7. The percent control[a] of wild oats with barban at various stages of development in five crops at Saskatoon, 1959. The herbicide was applied with a logarithmic sprayer.

Crop	Stage of development (number of leaves)				
	1½ to 1¾	1¾ to 2	2¼ to 2¾	3 to 3½	3½ to 4
Barley	2.0 – 1.4 / 60	1.5 / 95 1.1 / 90 0.9 / 75	2.0 – 1.5 / 80	1.2 / 95 1.0 / 90 0.8 / 75	–
Wheat	–	2.0 / 50	2.0 / 50	–	–
Oats	–	1.0 / 95 0.7 / 90 0.6 / 75	–	–	–
Rapeseed	–	1.5 / 90 1.1 / 85	2.0 / 75	–	2.0 – 1.6 / 50
Flax	–	1.5 / 85 1.1 / 60	2.0 – 1.5 / 75	–	2.0 / 0

[a]The numerator of the fraction represents the rate of application (lb/A) and the denominator the resulting percent control.

bility but damage was not visible to any of the other crops at any stage of development at the highest rate applied.

In greenhouse tests in which wild oats were free from competition, 1.5 lb/A applied at the 1½ to 1¾ leaf stage caused marked growth depression. After three weeks, 10 percent of the plants died. Of the survivors, the first leaf (and sometimes the second leaf) dried up, but the third and fourth leaves continued to develop. Barban inhibited crown root development on more than 50 percent of the surviving wild oat plants. The remainder again initiated crown root development.

DISCUSSION

There are several factors which must be considered before a herbicide is acceptable for commercial use. Some herbicides are not selective enough to control wild oats without damaging crops. Rates required for desired results may not be economically practical for the commercial producer. Uniformity of results may be lacking as a result of variations in climate and soil. Post-emergence herbicides have certain advantages over pre-emergence herbicides, particularly where effectiveness is contingent upon soil incorporation. Variations in soil texture, organic matter, microflora, permeability, and base exchange capacity, and the influence of variable soil temperature and moisture upon them, are important in explaining inconsistencies observed with soil incorporated herbicides. There is also the psychological advantage with the post-emergence herbicide of spraying wild oats "where they are" instead of "where they were".

Tetrachlorobenzene is toxic to wild oats, but certain limitations attend its use. Relatively heavy rates are required to control the weed, often resulting in crop damage. The wettable powder is difficult to apply and perhaps limits the selectivity of the material. The herbicide kills developing seedlings but does not sterilize the remaining caryopses in the soil. Losses due to evaporation and leaching of the herbicide may contribute to this failure.

Simazine kills wild oats, but lacks the selectivity necessary for successful use in grain crops in western Canada. The liquid formulation was more effective than the granular formulation.

Occasionally CDAA was sufficiently selective in crops of barley and flax to kill germinating wild oat seeds without significantly damaging the crop. The results, however, were widely variable, occasionally providing excellent control at 2 lb/A (8) or little control at 12 lb/A. These results were corroborated by several workers in western Canada in 1957. Results varied from excellent to poor, with the granular formulation being somewhat more reliable than the liquid (12). At Saskatoon this herbicide appeared to be less effective where moisture was in short supply during the growing season.

EPTC is fairly consistent in the control of wild oats when applied in spring, but with the exception of flax, the selectivity of the herbicide in crops is not consistent.

Barban is the first selective, post-emergence wild oat killer to be effective. The results, however, were not consistent, perhaps since the extremely dry growing conditions and poor stands of seeded crops did not represent typical conditions of moisture or competition. The more favorable results at lower rates which have been reported from other locations would suggest that moisture is an important factor. Results from 12 locations revealed that adequate control was obtained at a rate of 1 lb/A or less without damage to wheat or barley (14). Consequently the National Weed Committee (Western Section) released barban to the grower on a trial use basis in 1960 for wild oat control in barley, wheat, sugar beets, rape and sunflowers. It was reported in 1959 by Friesen (9) that the use of fertilizer and by Corns (6) that vigorous competition by the crop improve the effectiveness of the herbicide. The stage of development appears to be critical, with applications between 1 and 1½ leaves being more effective than applications between 2 and 3 leaf stages (14). At Saskatoon, applications at the 1¾ to 2 leaf stage (five to six days after emergence) were most effective. It is at this stage in the development of wild oats that crown roots are normally initiated. It would appear therefore, that applications just prior to, or in the very early stages of crown root development were most effective in inhibiting their development and controlling the weed.

2,3–DCDT provided consistently efficient control of wild oats over a wide range of environmental conditions. The weed was controlled adequately with 1.5 lb/A on stubble and summerfallow, in soils which varied in texture from loam to silty clay loam, in soil moisture conditions which were dry, moist or wet in seeding time, and in growing seasons which varied between inadequate moisture (3.5 in) to optimum (7.5 in). Trials which were conducted with 2,3–DCDT in 32 tests in western Canada during 1959 indicated that 83 percent of the wild oats were eliminated at a 2 lb/A rate (14). On the strength of these data, the National Weed Committee (Western Section) released 2,3–DCDT to growers for wild oat control in flax and supported a "trial recommendation" in barley, rapeseed, sugar beets and sunflowers. Selectivity could be improved, but the 1.5 lb/A rate would seem to be safe in crops of flax, rapeseed, and barley, and shows promise for use in wheat. Crop damage did not appear to be significantly increased when the delay between spraying and seeding was reduced from three weeks to three days to two hours. A single disking appeared to be adequate soil incorporation of the herbicide on summerfallow, but two diskings appeared to be necessary on stubble land.

SUMMARY

During the last decade, considerable research effort has been directed to the development of selective herbicides for wild oat control in grain crops. Of an average of 26 herbicides which have been tested each year, the pre-seeding herbicides 2,3–DCDT and EPTC and the post-emergence herbicide barban are those which

show most promise. Of these three, most consistent results have been obtained with 2,3–DCDT, which controlled wild oats at 1.5 lb/A in a wide range of environmental conditions without damage to flax, rapeseed or barley. Barban shows promise for the control of this weed in wheat, barley and rapeseed.

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Degradation of C^{14}-Labeled Simazine by Plants and Soil Microorganisms[1]

MOHAMED TAWFIK H. RAGAB[2] and JOHN P. MCCOLLUM[3]

INTRODUCTION

INVESTIGATIONS showing the effective use of simazine [2-chloro-4,6-bis (ethylamino)-*s*-triazine] as a selective herbicide in several crops particularly in corn has resulted in a demand for information about its degradation in plants. It is extremely important then to know if toxic residues remain in plants. Evidence to the contrary would be obtained if plants treated with simazine uniformly labeled with carbon-14 in the triazine ring were found to respire radioactive carbon dioxide.

The purpose of the investigation was to determine if a resistant plant (sweet corn) is capable of metabolizing the carbon in the triazine ring of simazine to carbon dioxide. A further purpose was to determine if resistance in plants might be due in part to their ability to metabolize the herbicide.

LITERATURE REVIEW

Corn has been shown to possess a high physiological resistance to simazine (3, 4, 12, 16), while barley and rye (16), wheat (10), and cucumber (4) have been found to be very susceptible to injury.

Roth (10) stated that freshly pressed maize juice was able to decompose simazine, while that of wheat was practically without effect. He concluded that the resistance of corn to simazine might be due to an enzyme system which is able to change the herbicide into a non-biologically active product.

Gast (5) found that *s*-triazines inhibited photosynthesis and consequently prevented starch formation when applied to *Coleus belamei* and *Tropaeolum majus*.

Similarity between the phytotoxic reactions of the urea herbicides and simazine has been indicated as both interfered with carbon dioxide assimilation and were inhibitory to the Hill reaction (1, 2, 5, 7).

In the presence of simazine photosynthesis in *Elodea* was inhibited and its oxygen uptake was increased over that of normal plants (10). No destruction of cellular elements was observed, and histochemical examination indicated that the dehydrase systems of the cells were active in the presence of simazine.

Knüsli (7) reported that maize was protected by possessing an

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[2]On leave from the College of Agriculture, University of Alexandria, Alexandria, Egypt, U.A.R.

[3]Professor of vegetable crops, University of Illinois.

enzyme system capable of deactivating simazine and related compounds. The same author added that the action of simazine might be due to a photosynthesis-inhibiting metabolism, while permitting respiration.

Wakonig and Arnason (14) showed that 2-chloro-4, 6-bis (ethylamino)-*s*-triazine penetrated the nucleus and produced conspicuous changes in root chromosomes. Roots of *Vicia faba* treated for 12 hours in a 10^{-5} M solution of the triazine at 20°C had few aberrations at the end of the treatment, but after about 12–36 hours anaphase aberrations became numerous. Most of the breaks and exchanges occurred in heterochromatic regions. The germination of barley seeds was inhibited nearly 100 percent by a 24-hour treatment with 10^{-3} M simazine.

The activity of triazine herbicides, dependent on the presence of moisture, was related to the absorptive powers of the soil to which applied (7). A true elimination of simazine occurred, depending on the soil type, and thus the *s*-triazines were not found to be harmfully persistent.

MATERIALS, METHODS, AND RESULTS

Both nonradioactive (99.9 per cent) and carbon–14 labeled simazine[4] were used. The latter, uniformly labeled in the triazine ring, had a specific activity of 0.83 μc/millimole. The plants studied were Golden Security sweet corn and the Marketer variety of cucumber.

The method used for collecting carbon dioxide evolved from treated plants or soil microorganisms consisted of sweeping the gas from an inclosed chamber into an alkaline solution (Figure 1). The whole apparatus was clamped tightly and installed on a wooden base in the greenhouse. The plants were supplied with nutrient "solution 2" of Hoagland and Arnon (6).

All radioactivity measurements were made by a Tricarb liquid scintillating counter. Scintillation countings were made in 5-dram capacity cylindral scintillation vials fitted with tin foil screw caps. Carbon dioxide trapped in absorbing tubes M_1 and M_2 was precipitated as barium carbonate. The latter was radioassayed as suspension in gel scintillator (15) prepared by adding 25 mg of a thixotropic substance[5] to a liter of liquid scintillator in a blendor and homogenizing for about three minutes. The liquid scintillator was made by dissolving 3 gm of 2,5–diphenyloxazole in one liter of redistilled reagent grade toluene.

Radioactive barium carbonate of known specific activity was used to check the efficiency of the samples of barium carbonate suspension. The efficiency of the counter was checked with an external standard toluene–7–C^{14}. The same radioactive toluene was used as an internal standard for checking the quenching of all assayed samples and

[4]Supplied by Geigy Agricultural Chemicals.
[5]Thixcin (Baker Castor Oil Co., New York, N. Y.).

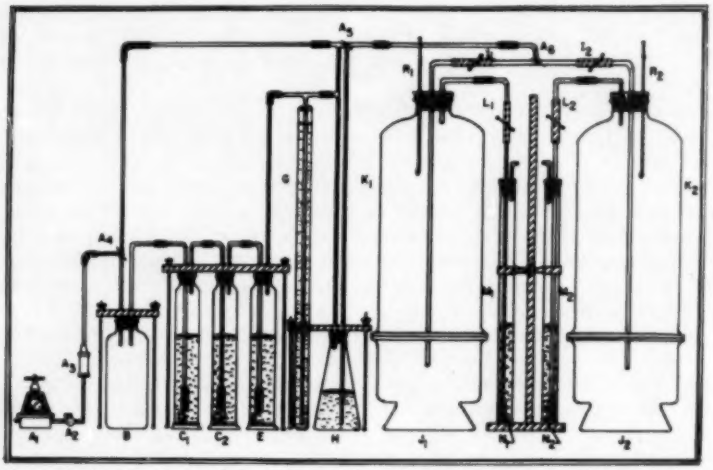

Figure 1. Apparatus used for determining the degradation of Simazine–C^{14} to carbon–14 dioxide by plants and nutrient microflora. A_1, air pressure regulator; B, trap; C_1 and C_2, 15% NaOH; E, $Ba(OH)_2$; G, barostat tower; H, nutrient solution; K_1 and K_2, inclosed chambers; M_1 and M_2, CO_2 absorption tubes.

solvents. The counts per minute were corrected for each sample as follows:

$$\text{Correction factor (C.F.)} = \frac{\text{Counts per min. (Internal Standard)}}{\text{(Counts per min. (Sample + Internal Standard)} - \text{Counts per min. (Sample)}}$$

A high vacuum line (Figure 2, without the wet combustion apparatus K) was used for freeze-drying plant parts and isolating any suspected volatile components in them or in the nutrient culture residue after the termination of the experiment. The vacuum line in conjunction with wet combustion apparatus (Figure 2) was used for oxidizing plant residues and vacuum distilling carbon dioxide into hyamine hydroxide prepared according to Passmann, Radin and Cooper (9). The combustion liquid used was that of Van Slyke, Folch and Plazin (13) and contained potassium iodate.

Isolated volatile compounds in the vacuum line were gas chromatographed with Vapour Fractometer Model 154, Perkin-Elmer corporation, and Speedomax Type G, Leeds and Northrup Company. The column used was didecylphthalate on celite.

Micro-Sohxlet apparatus was used for extracting radioactivity from all plant parts except corn roots, which were extracted in semi-micro-Sohxlet apparatus. The radioactive plant extracts were chromatographed on Whatman No. 1 chromatographic paper. The descending method was used and 50 percent *p*-dioxane employed as a developing solution. Radioactivity on paper chromatograms was assayed by the radioactivity scanning device "Actigraph".

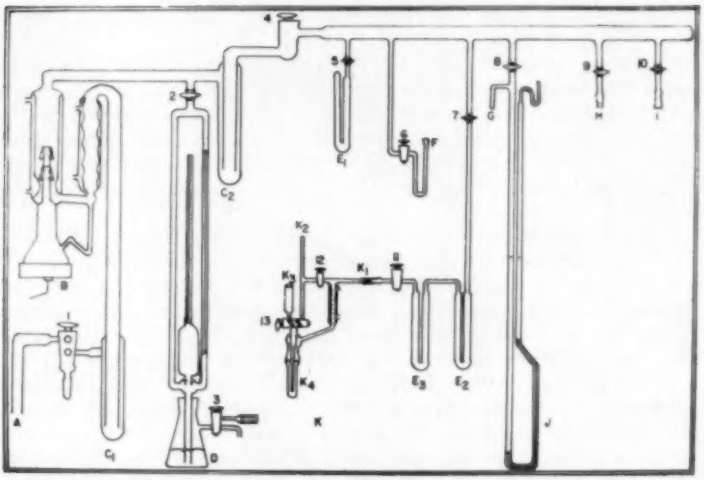

Figure 2. High vacuum line in conjunction with wet combustion apparatus. A, Fore pump; B, mercury diffusion pump; C_1, C_2, E_1, E_2, E_3, and G, traps; D, McLeod gauge; 1–13, stopcocks; J, manometer; K, wet combustion apparatus.

Experiment No. 1 dealt with sweet corn plants and was conducted to determine if they were capable of metabolizing simazine. Sweet corn was germinated in clean white sand in a greenhouse flat. After one week the plants were removed and their roots washed with water. Two groups of eight plants each were transferred separately into 5 in. porous dishes. Glass wool was placed over the roots and between the plants to keep them growing upright. The glass wool was moistened with nutrient solution and the dishes were then placed in a tray containing about one inch of nutrient solution. In this way the roots of the plants were continuously moistened with nutrient solution. After seven days the groups of plants were transferred to containers J_1 and J_2, (Figure 1) the bottoms of which had been plated with a thin layer of simazine. Simazine (2.42 mg, about 2 pounds per acre) was placed in container J_1 and 40 ml of chloroform added to dissolve it. The chloroform was then evaporated in a current of air leaving a very thin film in the bottom. Container J_2 was treated in the same way with 10 μc (2.42 mg) of radioactive simazine. After plants were placed in J_1 and J_2 sufficient nutrient solution to moisten the glass wool was added and the chambers tightly closed.

During daytime stopcock A_4 was adjusted to allow unscrubbed air to pass through K_1 and K_2 to provide carbon dioxide for photosynthesis. It was readjusted for scrubbing at night to obtain respired carbon dioxide from the plants. Before attaching tubes M_1 and M_2 carbon dioxide-free air was circulated through the inclosed chambers

for about 10 minutes to sweep the closed system of any carbon dioxide not respired.

Absorbing tubes M_1 and M_2 each containing 50 ml of approximately 1 N sodium hydroxide were attached to the apparatus. Pinchcocks I_1, I_2, L_1 and L_2 were adjusted to let air bubble gently and at approximately the same rate through N_1 and N_2. At sunrise tubes M_1 and M_2 were detached from the system and both passages from each tightly closed. Stopcock A_4 was then readjusted to eliminate scrubbing.

The duration of the experiment was eleven days. Four collections of carbon dioxide were made in separate tubes. The first collection included the gas for five nights, each of the subsequent three for two nights. Each collection was precipitated separately as barium carbonate with barium chloride in the presence of ammonium chloride. About 100 mg of barium carbonate screened through a 1 × 1 in. 80-mesh brass screen into the scintillation vial was accurately weighed and radioassayed in 14 ml of the scintillation gel. Barium carbonate from the carbon dioxide of plants treated with nonradioactive simazine served as background. Results of this experiment are summarized in Table 1. It can be seen that corn plants apparently absorbed simazine and degraded some of it to carbon dioxide.

Table 1. Simazine–C^{14} degraded to carbon–14 dioxide by sweet corn plants.

Nights sampled (14 hrs.)	Per sampling	Cumulative	Per sampling	Cumulative
	μc	μc	Mg/gm of dry plant	
1– 5	.0072	.0072	4.7	4.7
6– 7	.0010	.0082	0.6	5.3
8– 9	.0011	.0093	0.7	6.0
10–11	.0017	.0110	1.1	7.1

When the results from experiment No. 1 indicated that a resistant plant (sweet corn) could metabolize simazine–C^{14} to $C^{14}O_2$, a second experiment with both resistant and susceptible plants was conducted. In this experiment corn and cucumber were germinated as described before. Ten plants of corn and fifteen of cucumber were placed in respective containers J_1 and J_2. Each group of plants was supplied with 10 μc of radioactive simazine as in experiment No. 1. Expired carbon dioxide was collected for eight consecutive nights. The gas for each two nights was collected together in 50 ml of 1 N sodium hydroxide. Radioactivity in the alkali samples was assayed as in experiment No. 1. At the end of the experiment the cucumber plants had become chlorotic and were producing adventitious roots on the stems above the nutrient solution, indicating toxicity of simazine to the roots themselves. The corn plants grew and roots seemed uninjured. It can be seen from Figures 3 and 4 that the susceptible plant, cucumber, as well as corn, can metabolize simazine to carbon dioxide. For the first two nights (first collection) of the experiment, activity from the cucumber plants was much higher than that from corn, but the corn continued to grow and produce

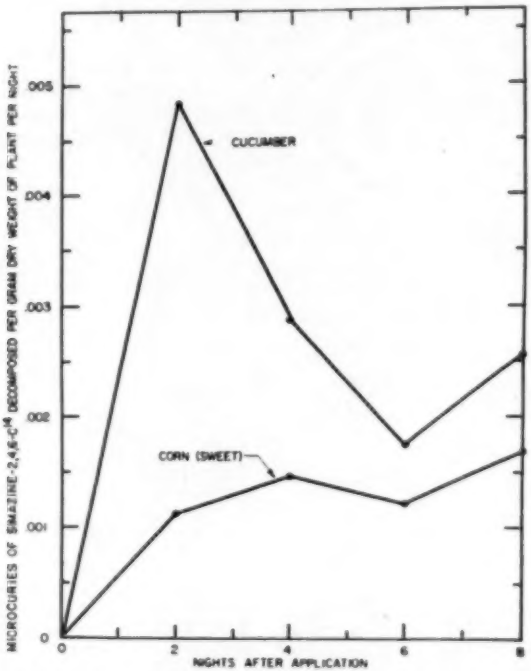

Figure 3. Degradation of labeled simazine by corn and cucumber plants.

extensive roots while the cucumbers did not. In the next three collections, activity from the cucumber gradually decreased but that from the corn gradually increased.

At the termination of the experiment, plants, including all roots, were removed for assay. The chambers were then closed and the carbon dioxide from the substrate collected for three days to check for activity that might possibly be produced by the substrate. The amounts of carbon dioxide collected were much lower than with plants but specific activities were higher. When calculated for 28 hours (approximately equivalent to two nights) the substrate for corn decomposed 0.36×10^{-6} and that from cucumber 0.51×10^{-6} μc of simazine.

Immediately after removing the plants, leaves and stems were separated from roots and each placed in respective 100 ml round bottom flasks. At the end of the experiment without plants the nutrient residues were also placed in 100 ml round bottom flasks. The six flasks for corn and cucumber plants and nutrient residues were attached separately to the vacuum line (Figure 2) to freeze dry the samples and isolate and volatile compounds present. No volatile fractions were obtained from the leaves and stems of the plants.

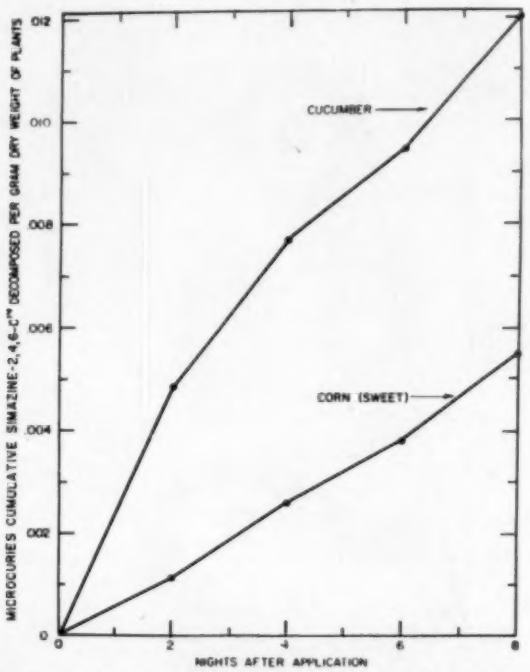

Figure 4. Degradation of labeled simazine by corn and cucumber plants.

Very low activity was found in the isolated volatile gases from roots and nutrient residues. When these volatile fractions were gas chromatographed, they showed negative results, indicating that the activity was due to carbon dioxide.

The tops and roots of corn and cucumber were transferred from the flasks to small metal cans and further dried in an oven at 75°C for 24 hours. Each sample was ground and extracted three times, each continuing for 24 hours. Chloroform was used for the first two extractions and distilled water for the third. Each chloroform extract was transferred quantitatively to a 25 ml volumetric flask and made to mark with absolute ethanol. A 0.5 ml aliquot of this solution was diluted to 25 ml with redistilled toluene for assay. The water extracts of all but corn roots were transferred quantitatively to 25 ml volumetric flasks and diluted to the mark with distilled water. The water extract from corn roots was transferred to a 250 ml volumetric flask.

For assaying the radioactivity of the chloroform extracts 0.1 ml of each was transferred to a scintillation vial and 14 ml of liquid scintillator was added for counting in the scintillation counter. The water extracts were assayed in the same way except that 6 ml of

absolute ethanol and 8 ml of liquid scintillator was added. Data for radioactivity of the extracts from plants are presented in Figure 5. Radioactivity in both chloroform and water extracts indicates the presence of unchanged simazine as well as its metabolic breakdown products in treated plants. Activity in the chloroform extracts from leaves and stems and from roots of corn were very similar, indicating the homogenous distribution of activity in the entire plant. In cucumber the activity in the chloroform extracts of roots was 17 times as high as that in the stems and leaves. The high activity in the chloroform extracts of the roots of cucumber was in contrast with the low activity in those of the roots of corn. The degenerated condition of the cucumber roots at the time of sampling might have contributed to this difference.

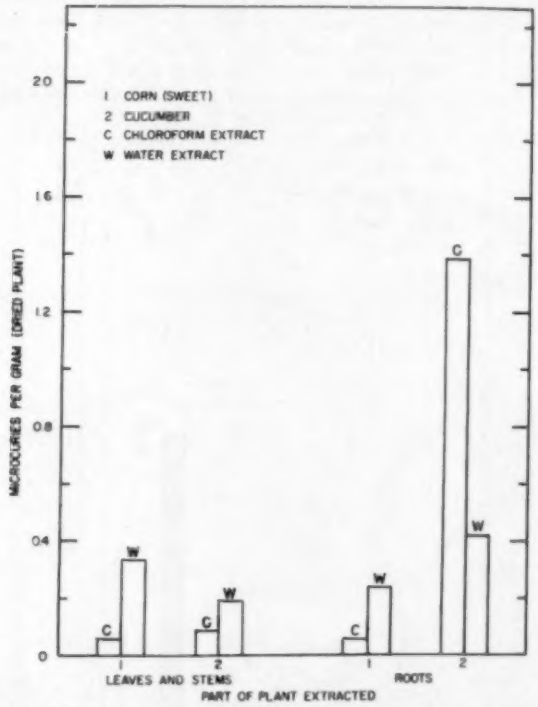

Figure 5. Radioactivity in extracts of corn and cucumber plants treated with simazine-C^{14}.

The first chloroform and water extracts of the plant parts were chromatographed and the chromatograms were assayed by the radioactivity scanner device. The results show activity in the water as well as the chloroform extracts indicating degradation products of

simazine. The R_f values were inconsistent and seemed unreliable in the presence of impurities.

The extracted corn and cucumber tops and roots were dried in the oven, weighed and ground. About 10 mg of each dried plant part was oxidized to carbon dioxide in the wet combustion apparatus (K) attached to the high vacuum line through joint k_1 (Figure 2). The line was filled with helium at atmospheric pressure. The dried plant material was boiled gently in the combustion liquid for 4 minutes and the evolved gases were swept with helium into traps E_2 and E_3 cooled with liquid nitrogen. Sweeping with helium was continued for another 4 minutes. The two traps were then evacuated to 10^{-4} mm mercury and their contents, free of water, were vacuum distilled at room temperature into a small vessel containing hyamine hydroxide. The contents of the vessel was transferred quantitatively with 14 ml of liquid scintillator into a scintillation vial, and counted in the scintillation counter. Figure 6 gives μc of radioactivity per gm of dry plant tissue persisting after the three exhaustive extractions. The data show greater activity in cucumber than in

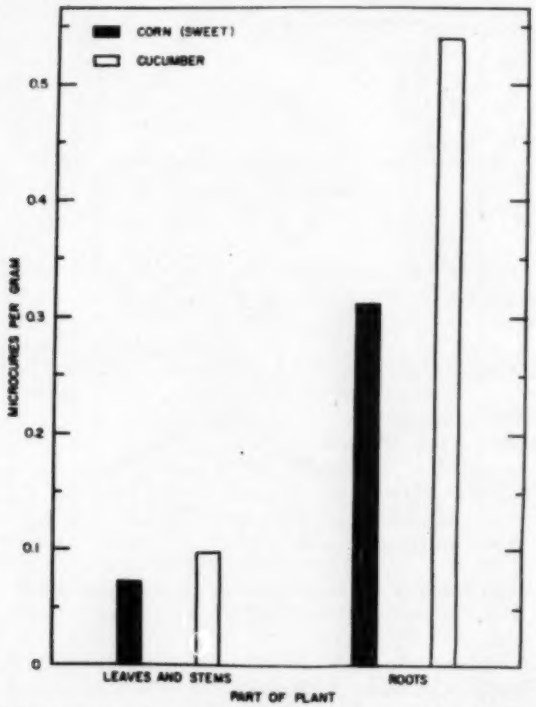

Figure 6. Radioactivity in extracted residues of corn and cucumber plants treated with simazine–C^{14}.

corn. They also show greater activity in roots than in leaves and stems.

The radioactivity emanating from the substrate after plants treated with simazine–C^{14} had been removed indicated that the microflora of the nutrient solution might play a role in the degradation of simazine. An experiment to test this possibility was devised. On the bottom of each of the containers J_1 and J_2 was deposited 1.21 mg of simazine, one labeled with carbon–14 (5 μc) and one unlabeled for background. Leachings from sand which had been used to germinate corn and cucumbers were used to moisten rock wool placed in contact with the labeled and non-labeled herbicide. The system was closed and carbon dioxide-free air was passed over the inoculated simazine in both chambers for eight days. Evolving carbon dioxide was trapped in tubes M_1 and M_2 containing N sodium hydroxide. Radioactivity assayed as previously described indicates that .005 μc of simazine was degraded to carbon dioxide during the eight days by a substrate without plants.

As a result of this experiment it became more evident that microorganisms play a role in degrading simazine. To eliminate the possible effect of plant residues or exudates on the degradation of

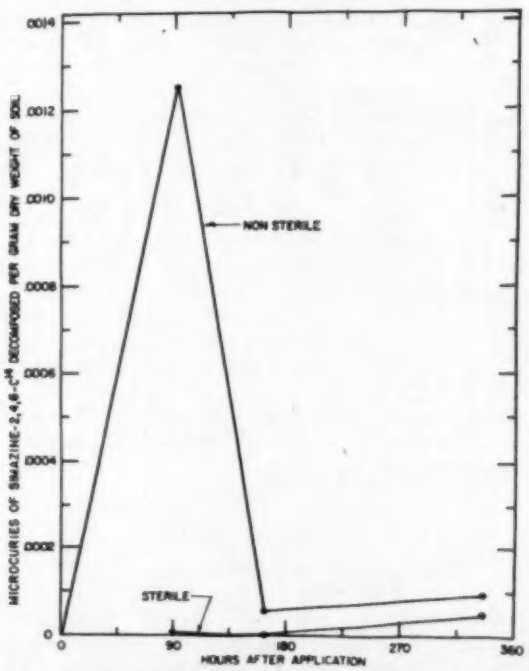

Figure 7. Degradation of labeled simazine by soil microorganisms.

simazine a further experiment was made using soil on which no plants had grown for more than a year. Two 100 gm samples (moist) were placed in one liter Erlenmeyer flasks. One was autoclaved for 20 minutes at 120–121°C on three consecutive days. Other necessary glassware was sterilized in a closed paper bag.

Ten microcuries of simazine–C^{14} was dissolved in about 40 ml of chloroform and carefully introduced into the sterilized flask. The chloroform was evaporated by mild heating and air passed through the flask via tubes guarded with dry cotton plugs. In the second flask 10 μc of simazine–C^{14} was precipitated on the bottom before the soil was added. The two were attached to apparatus (Figure 1) in place of k_1 and k_2. Scrubbed and filtered air was passed through flasks and carbon dioxide subsequently removed with sodium hydroxide. Assays were made after 91, 163, and 335 hours, after which the experiment was terminated.

The data (Figures 7 and 8) show very little decomposition of simazine by the sterilized soil and none until the last sampling. In the unsterilized flask a high rate of decomposition by 91 hours was followed by a greatly reduced rate.

At the end of the experiment the soil in each flask was streaked

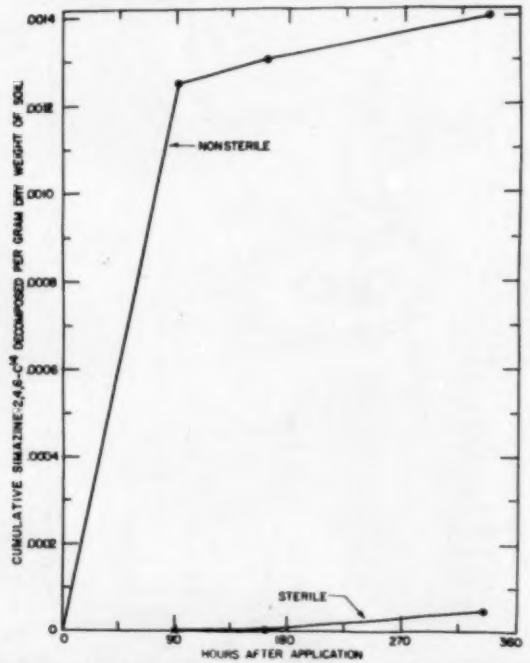

Figure 8. Degradation of labeled simazine (milicuries) by soil microorganisms.

on an agar plate and the autoclaved sample found to be essentially sterile.

DISCUSSION

The production of carbon–14 dioxide by corn and cucumber plants treated with simazine–C^{14} clearly demonstrates that both resistant and susceptible plants decompose simazine to a nontoxic product.

The fact that cucumber metabolized simazine at a more rapid rate than corn dispels the suggestion (11) that toxicity is associated with inability to metabolize the herbicide. The marked decrease in rate of degradation by cucumber may be associated with decreased photosynthetic efficiency as the plants deteriorate. A low rate at the third sampling (Figures 3 and 4) was perhaps due to low light intensities during that period.

The wide distribution of radioactivity in both corn and cucumber plants is evidence that simazine is readily absorbed by different plants. It seems therefore, unlikely that selective toxicity of simazine is a matter of absorption. The cucumber may, however, absorb simazine at a more rapid rate than corn as indicated by greater radioactivity in the plants and more rapid degradation. The fact that cucumber plants growing in nutrient-moistened glass wool with simazine produced adventitious roots on the stems indicates that the herbicide is toxic to the roots of plants.

The presence of activity in the plant residues after three exhaustive extractions clearly demonstrates the anabolism of $C^{14}O_2$ or other radioactive degradation products of simazine.

The role played by soil microorganisms heretofore thought unimportant in decomposing simazine has been shown to be very significant. During the first 91 hours the rate of decomposition of simazine–C^{14} to $C^{14}O_2$ was high, after which a rapid drop occurred. This might have been due to a toxic effect of the simazine on the soil microorganisms in contact with it. Simazine was precipitated on the bottom of the Erlenmeyer flask and not mixed with the soil. As a result the microorganisms in contact with the concentrated simazine might after some delay have been impaired by it.

Since simazine–C^{14} was uniformly labeled in the triazine ring, the evolution of $C^{14}O_2$ must have resulted from splitting the ring, indicating complete decomposition of the basic structure of simazine.

SUMMARY

Sweet corn and cucumber seedlings were grown in two inclosed chambers where they were treated with 10 μc simazine–2,4,6–C^{14}. Carbon–14 dioxide from these plants was collected and counted as barium carbonate in a gel scintillator with a scintillation counter.

Plant parts were extracted twice with chloroform and once with water. The data showed more activity in roots than in leaves and

stems, and more activity from cucumber extracts than from corn. The extracted plant parts, wet oxidized in a high vacuum line, revealed a similar trend.

Paper chromatography of extracted plant parts showed unchanged simazine in leaves and stems, and undetermined components having R_f values below that of simazine.

Results from sterile and nonsterile soils treated with 10 μc of simazine–C^{14} indicate that microorganisms play an important role in the decomposition of simazine in soils and may account in part for disappointing results from some field applications of simazine.

The use of a high vacuum line in conjunction with wet combustion apparatus was found to be especially suitable for radioassaying small samples of low activity.

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Substituted Urea Herbicides in the Control of Undesirable Hardwoods[1]

ROBERT G. MERRIFIELD[2] and THOMAS HANSBROUGH[3]

THE control of hardwood vegetation is an essential step in establishing pine on upland sites in North Louisiana. In some instances removal of all vegetation is necessary before pine seeding or planting can be done. This type of operation is usually accomplished by conventional land-clearing methods, which are often rather expensive. The use of chemicals as a means of hardwood control offers certain advantages not inherent in mechanical methods. In situations where species selectivity is not desired, the substituted urea herbicides might provide an economical means of vegetation control.

The three substituted ureas studied here were: 3–(*p*–chlorophenyl) –1, 1–dimethylurea (monuron); 3–(3,4–dichlorophenyl)–1,1–dimethylurea (diuron); and 3–phenyl–1,1–dimethylurea (fenuron)[4]. These herbicides are applied to the soil either as wettable powders or pellets. They are then taken up by the plant through the root system and enter into the transpiration stream. There is evidence that the plant is killed through the interference of the photosynthesis process at the light end of the reaction (1).

On medium- to light-textured soils, monuron and fenuron have provided control of scrub oaks at minimum rates ranging from 4 to 12 pounds of active ingredient per acre (3,9,15). Monuron was also successfully used to create openings for pine regeneration in Minnesota (4). Here, the rates applied were in excess of 16 pounds of active ingredient per acre.

Investigators have found that certain soil characteristics will reduce the effectiveness of urea herbicides. There is general agreement that decomposition by soil microorganisms is the most important factor affecting these materials (5,7,8,10,12). To lesser extent, leaching has been found to remove varying amounts of the herbicides from the effective root zones (2,5,7,11,13,14). Soil texture produces an indirect effect in that leaching has been found to be greatest in light soils (11), while microbial activity is greatest in heavy soils (7). Other factors of apparently minor importance that have been investigated include light, temperature, chemical decomposition, and volatilization (5,6,7).

METHODS AND MATERIALS

To test the effectiveness of substituted ureas on native hardwood species in North Louisiana, two experiments were established at

[1]Received for publication March 14, 1960.

[2]Assistant Professor, North Louisiana Hill Farm Experiment Station, Louisiana State University, Homer, Louisiana.

[3]Assistant Professor, School of Forestry, Louisiana State University, Baton Rouge, Louisiana.

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the North Louisiana Hill Farm Experiment Station in August 1955 and May 1956. For both investigations the study area consisted of a typical upland oak-hickory site, characteristic of the hills of this region. The soils of the test site were loamy fine sands with approximately 2.2% organic matter.

The initial study consisted of nine treatments which were randomized on one-tenth acre plots and replicated three times. A 33-foot buffer zone surrounded each plot to isolate the effects of the treatments. A one-fortieth acre sampling unit was located in the center of each plot. All woody vegetation within this area was identified and labeled as to species. Stand density averaged 3760 stems per acre, of which 90% were less than 4 inches d.b.h. The overstory species consisted mainly of white oak (*Quercus alba* L.), black oak (*Quercus velutina* Lam.), mockernut hickory (*Carya tomentosa* Nutt.), sweetgum (*Liquidambar styraciflua* L.), and blackgum (*Nyssa sylvatica* Marsh.). The understory was made-up of fringe-tree (*Chionanthus virginicus* L.), arrow-wood (*Viburum dentatum* L.), tree-huckleberry (*Vaccinium arboreum* Marsh.), and May haw (*Crataegus opaca* Hook. & Arn.). These 9 species comprised approximately 75% of the woody vegetation on the area.

In the first study each herbicide (monuron, diuron, and fenuron), with water as a carrier, was applied as a ground spray in strips using hand spray equipment at the rates of 4, 8, and 12 pounds of active ingredient per acre. The sprayed strips within each plot were approximately 1 foot wide with a 6-foot interval between strips. The actual concentration of the herbicides on the strips was about 7 times the per-acre rate assigned each treatment. One-year-old lobolly pine (*Pinus taeda* L.) seedlings were planted in the center of the non-treated areas in January 1956, 5 months after treatment.

The second experiment, established in May 1956, was located adjacent to the initial study on a similar site. In this study the urea herbicides applied were pelleted monuron and fenuron, and fenuron in wettable powder form. The rates of application were 4, 8, and 12 pounds of active ingredient per acre for the pelleted herbicides and 10 pounds per acre of fenuron wettable powder. The design of the study was the same as the previous one except that no sampling area was established, no underplanting was done, and the herbicides were broadcast over the entire plot. Mortality estimates were made by observing the percentage of kill on each plot.

RESULTS AND DISCUSSION

The results of the August 1955 study are based on the number of dead stems present on the sampling units at the time of final inventory made in April 1958, after all living vegetation had completely leafed out. The results of this inventory are shown in Table 1. It is readily apparent that none of the treatments was effective enough to warrant recommendation. Where the percentage of kill was relatively high, the major species involved were black oak. white oak, mockernut hickory, sweetgum, and blackgum.

Table 1. The effect of substituted urea herbicides on upland hardwoods.

Lb/A of herbicide applied	No. of stems present per 1/40th acre		No. of stems dead per 1/40th acre		Percent dead	
	Less than 4" dbh	Greater than 4" dbh	Less than 4" dbh	Greater than 4" dbh	Less than 4" dbh	Greater than 4" dbh
Monuron						
4	232	21	11	0	4.7	0
8	276	25	23	5	8.3	20.0
12	196	44	13	20	6.6	45.4
Diuron						
4	278	37	10	1	3.6	2.7
8	238	29	9	0	3.8	0
12	264	21	16	1	6.1	4.8
Fenuron						
4	265	29	3	3	1.1	10.3
8	240	25	18	1	7.5	4.0
12	213	35	16	13	7.5	37.1

Early observations of the initial study area indicated that promising results could be anticipated on the plots receiving the heaviest chemical treatment. Immediately following the application of the herbicides, several trees experienced complete defoliation with the leaves re-emerging prior to natural leaf cast in October and November. The defoliation and leaf reemergence process was repeated at least twice during the next (1956) growing season. By June 1957 it was apparent that only a few of the stems previously thought to be killed were actually dead. This condition remained static until the final inventory was taken in 1958. The underplanted loblolly pine did not appear to be affected by the herbicides.

It is difficult to isolate a single factor as the cause of the ineffectiveness of the herbicides. The fact that the sprayed strips comprised only 15% of the total plot area could have had some bearing on the results obtained. Because of the low solubility of these chemicals (monuron 240 ppm., diuron 40 ppm., fenuron 2400 ppm.) presumably no lateral and very little downward movement took place after they entered the soil, consequently the intervals between the sprayed strips remained essentially free of the herbicides. The lack of mortality in the underplanted loblolly pine supports this assumption. Table 1 also shows that where the percentage of kill was relatively high the trees were of sufficient size to have their root systems crossed several times by the sprayed strips.

The ineffectiveness of these materials in killing the undesired species could have resulted also, from changes in the herbicides after exposure to the soil. While laboratory analysis showed only 2.2% organic matter in the upper 6 inches of mineral soil, it is felt that this figure may be slightly misleading as an indicator of the degree of microbial activity actually existing on the test area. There was considerable hardwood litter on the ground, with a thin layer of decomposed organic material beneath it. This amount of organic matter may have been sufficient to induce biological degradation of the herbicides.

During the year following the application of the herbicides, a total of 42 inches of rain was received. This amount was fairly well distributed and is approximately 10 inches below the yearly average for this region. Leaching studies have shown that even abnormally high amounts of water will move only a small percentage of the urea herbicides below 8 inches from the ground level. For this reason, the effect of leaching is not considered to be important in this study.

The effect of the herbicides on the vegetation in the second study was generally the same as that encountered in the first one. Observations made in August 1956 and June 1957 showed the same pattern of symptoms, i.e., repeated defoliation with malformed, necrotic leaves produced after each leaf cast. Pelleted fenuron at 12 pounds per acre, however, did result in about a 75% kill. On these plots a great number of the smaller stems were killed, confirming the suspicion in the first study that the herbicides did not come into direct contact with the root systems not directly under the surface on which the chemical was applied.

Based on the results of this study, the fenuron pellet appeared to offer the best possibility as a means of controlling unwanted vegetation. This was also found to be true in tests with fenuron conducted in Texas (3). It is doubtful, however, that any of the herbicides tested could be economically used by forest landowners. The cost of pelleted fenuron at 12 pounds per acre is approximately $57.00. The other two are only slightly less. Only if vegetative control could be obtained at rates in the vicinity of 1 to 3 pounds per acre, could these materials be considered practical under the present economic limits of southern forest management.

SUMMARY

In August 1955, monuron, diuron, and fenuron were applied to one-tenth acre plots of hardwood vegetation in North Louisiana at 4, 8, and 12 pounds per acre. They were applied as ground sprays in 1-foot strips at 6-foot intervals. Broadcast treatments of pelleted monuron and fenuron at 4, 8, and 12 lb/A and fenuron as a wettable powder at 10 lb/A were applied to one-tenth acre plots in May 1956.

Initially a complete kill on the high rate plots appeared very likely. White oak, black oak, mockernut hickory, sweetgum, and blackgum were most affected by the treatments. Many of the trees lost their leaves only to have them re-emerge before natural leaf cast in the fall. The 1956 growing season was characterized by two more leaf casts. By June 1957 it was evident that, except for broadcasted fenuron pellets at 12/A, the herbicidal effect of the materials was almost negligible.

The ineffectiveness of the herbicides was thought to be, in part, the result of the method of application. Decomposition of the herbicides by soil microorganisms was considered to be another element that might have inhibited the action of the materials.

Leaching was not regarded a limiting factor in the results of the study.

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Thistle Control with Cultivation, Cropping and Chemicals[1]

LYLE A. DERSCHEID, RUSSEL L. NASH and GAIL A. WICKS[2]

CANADA thistle and perennial sowthistle have been given several names by various authors (2). However, it appears that the Canada thistle used in this study is generally called *Cirsium arvense* (L.) Scop. (2, 5, 12) and the perennial sowthistle was a mixture of *Sonchus arvensis* L. and *S. uliginosus* Bieb. (2, 5). The two species of sowthistle are very similar. However, *S. arvensis* has "long glandular-hispid peduncles and involucres covered with lead colored glandular phyllaries" (5) and a chromosome complement of 54, while *S. uliginosus* has "slenderly turbinate to cylindric pale involucres and glaborous white-margined phyllaries" (5) and a chromosome complement of 36.

All 3 species are perennials that spread by means of horizontal roots and seeds. They have umbellate heads. The flowers of Canada thistle are purple and those of sowthistle are yellow. All produce copious amounts of pappus. Seeds attached to the pappus are disseminated over large areas by air currents.

One or more varieties of Canada thistles can be found in most of the northern states of the United States and the southern parts of most of the Canadian provinces (5). Heavy infestations are found in Ohio, Illinois, Indiana, Michigan, Wisconsin, Minnesota, Iowa, North Dakota and South Dakota, while lighter infestations are found in Nebraska and Missouri (9), and it is more common than any other weed in Montana, Idaho, Oregon and Washington (7). Perennial sowthistle is, in general, common to the Dakotas, Minnesota, Wisconsin and northern Iowa and Illinois (9). Although *S. arvensis* is generally thought to be the more common species, *S. uliginosus* is more common in North Dakota (11) and western Canada (6).

Canada thistle is dioecious and sowthistle is monoecious, but both are cross pollinated (2). Single plants propagate by means of roots and seeds and develop into patches. Seeds are also scattered, which gives a sprinkling of plants throughout the landscape. The density of the infestation is related to the distance from the parent patch, which creates a different problem than that associated with leafy spurge, Russian knapweed, hoary cress or field bindweed. Although the parent patches (weed nurseries) are similar to infestations with the other weeds, many acres are infested with sprinklings of thistles.

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[2]Agronomist, South Dakota Agricultural Experiment Station; Director of Agricultural Chemicals Research, Guth Chemical Co. (formerly Graduate Assistant at South Dakota); and Assistant Agronomist, Nebraska Agricultural Experiment Station, North Platte (formerly Graduate Assistant at South Dakota), respectively.

Such light infestations make it difficult to justify the use of expensive elimination measures. They do affect crop yield, however, especially in areas of limited rainfall. In one test an infestation of 2 Canada thistle plants per square yard reduced wheat yields 18 per cent, while 19 plants reduced the yield 36 per cent[3].

Trends in organic root reserves of thistle roots are similar to those of field bindweed and leafy spurge (1, 13). Therefore, it would appear that methods used for controlling other weeds might be effective for thistles. Many combinations of cultivation, crops and chemicals tested on field bindweed, leafy spurge, Russian knapweed and other weeds were reviewed or tested by Derscheid et al. (3, 4) and Rogers (10). Similar combinations tested on Canada thistle were reviewed or tested by Hodgson (7), Rogers (10) and Willard (14) and the response of Canada thistle to 2,4–D was reported by Rasmussen (8).

These reports indicated that thistles could be killed while crops were growing, if the area was cultivated properly when not occupied by a crop and if the weeds were sprayed with 2,4–D in crops tolerant to the chemical. The objectives of the study reported here were to determine ways of eliminating large infestations while crops adapted to South Dakota were being produced, as well as ways of eradicating small patches with chemicals.

EXPERIMENTAL PROCEDURE AND RESULTS

Twenty-five acres of land infested with Canada thistle and perennial sowthistle were leased during 1955 to study methods of eliminating these weeds. Five general types of experiments were conducted: (1) 1-year experiments comparing implements at several time intervals of cultivation for intensive cultivation; (2) 3-year trials involving annual crops, cultivation and 2,4–D or MCPA; (3) 3-year trials involving perennial forage crops, cultivation and 2,4–D or MCPA; (4) comparisons of soil sterilants applied at several rates on two dates; and (5) 1-year tests in which new chemicals were screened for possible use in controlling or eliminating these weeds.

Intensive cultivation.

A 1-year experiment was conducted during 1955. It included 7 intensive cultivation treatments replicated in a randomized block design. All plots were plowed during mid-April. Other operations were performed between June 5 and September 10. Three treatments included the use of a 7-foot duckfoot field cultivator equipped with nine 12-inch overlapping sweeps operated at a depth of 4 inches at 2-week (8 operations), 3-week (6 operations) and 4-week (5 operations) intervals. Three treatments included the use of a one-way disk operated at a depth of 4 inches at the same intervals. The seventh treatment included double disking with an 8-foot

[3]Unpublished data reported by E. S. Molberg in Res. Rep. Canadian National Weed Committee. p. 117. 1955.

tandem disk harrow operated at a depth of 3 to 4 inches every two weeks (16 operations). An identical experiment was conducted during 1956. All treatments killed over 99 per cent of both species of thistles. These results indicate that the duckfoot cultivator and one-way disk need not be used any oftener than every 3 or 4 weeks and that a tandem disk harrow can be substituted for them if used twice (double coverage) every two weeks.

Annual crops, cultivation and chemicals.

A 3-year experiment, in which various combinations of annual crops (oats, corn, flax, and sudangrass), intensive cultivation and selective herbicides (2,4–D or MCPA) were compared, was initiated during the spring of 1955. It included 48 treatments in 2 replications. The area was heavily infested with Canada thistle and moderately infested with perennial sowthistle. The number of plants of each species was counted annually on the same 4 one-square-yard areas of each plot during the first week of June. Counts in 1955 were made before any spraying or cultivating was done, counts in 1956 and 1957 were used to evaluate the previous year's treatment and counts in 1958 were made the spring after all the treatments had been completed. An identical experiment was initiated during 1956 and completed during June 1959. The plots were moderately infested with Canada thistle, but the sowthistle stand was too sparse to yield any reliable information. Thirty-six of the treatments and the percentage of Canada thistle killed by each are given in Table 1.

First year. All plots were seeded to Mo. 0–205 oats during April and sprayed during the first week of June with 2,4–D or MCPA in 12 gallons of water per acre. Three-fourths lb/A acid equivalent of an alkanol amine of 2,4–D was applied in the 36 treatments shown in Table 1. However, a similar amount of diethyl amine of MCPA was applied in 8 other treatments and ½ lb/A of ethyl ester of 2,4–D was applied in 4 others. The thistles were in the spring rosette stage of growth and the oats were in the 5- to 6-leaf stage of growth.

All treatments except 1 to 4 included some type of fall operation. The oats crop sprayed with ¾ lb/A of 2,4–D amine reduced the stand of Canada thistle 30 per cent. Treatments 5 to 8 included plowing with a moldboard plow during mid-October in addition to the June application of 2,4–D. This killed 54 per cent of the Canada thistles, indicating that the late fall plowing aided in the elimination of this weed. All eight treatments allowed the stand of perennial sowthistle to increase 30 to 50 per cent.

Treatments 9 to 12 consisted of two sprayings with ¾ lb/A of 2,4–D amine—one during early June and another in the stubble. Such treatment reduced the stands of Canada thistle and sowthistle 79 and 58 per cent respectively. The addition of a late fall plowing in treatments 13 to 16 reduced the stands 89 per cent and 81 per cent, indicating once again that the late fall plowing aided in reducing thistle stands.

Table 1. Percentage of Canada thistle eliminated by use of adapted annual crops, cultivation and 2,4–D (mean of two 3-year experiments).

Trt. No.	First year		Second year		Third year[c]
	Treatment[a]	Pct. kill	Treatment[b]	Pct. kill	Pct. kill
1		30	Repeat 1st yr.	88	100
2		30	2,4–D 6/20	0	95
3		30	2,4–D 6/20 & 8/20	84	100
4		30	2,4–D 6/20 & silage	82	98
5	plow 10/15	54	Repeat 1st yr.	66	50
6	plow 10/15	54	2,4–D 6/20	50	95
7	plow 10/15	54	2,4–D 6/20 & 8/20	92	100
8	plow 10/15	54	2,4–D 6/20 & silage	52	97
9	8/25	79	Repeat 1st yr.	97	100
10	8/25	79	2,4–D 6/20	41	85
11	8/25	79	2,4–D 6/20 & 8/20	96	100
12	8/25	79	2,4–D 6/20 & silage	83	99
13	8/25 plow 10/15	89	Repeat 1st yr.	100	100
14	8/25 plow 10/15	89	2,4–D 6/20	33	99
15	8/25 plow 10/15	89	2,4–D 6/20 & 8/20	92	98
16	8/25 plow 19/15	89	2,4–D 6/20 & silage	97	100
17	plow 8/11 cult. 9/5 & 9/25	88	Repeat 1st yr.	100	100
18	plow 8/11 cult. 9/5 & 9/25	88	2,4–D 6/20	62	92
19	plow 8/11 cult. 9/5 & 9/25	88	2,4–D 6/20 & 8/20	95	100
20	plow 8/11 cult. 9/5 & 9/25	88	2,4–D 6/20 & silage	87	98
21	plow 8/11 cult. 9/5 & 9/25	88	Cult., sudan, plow	99	99
22	plow 8/11 cult. 9/5 & 9/25	88	2,4–D 6/20	62	99
23	plow 8/11 cult. 9/5 & 9/25	88	2,4–D 6/20 & 8/20	95	99
24	plow 8/11 cult. 9/5 & 9/25	88	2,4–D 6/20 & silage	87	97
25	plow 8/11 cult. 9/5, 9/25 & 10/15	83	Repeat 1st yr.	98	99
26	plow 8/11 cult. 9/5, 9/25 & 10/15	83	2,4–D 6/20	19	99
27	plow 8/11 cult. 9/5, 9/25 & 10/15	83	2,4–D 6/20 & 8/20	97	100
28	plow 8/11 cult. 9/5, 9/25 & 10/15	83	2,4–D 6/20 & silage	77	100
29	plow 8/11, 2,4–D 9/25	88	Repeat 1st yr.	98	100
30	plow 8/11, 2,4–D 9/25	88	2,4–D 6/20	76	93
31	plow 8/11, 2,4–D 9/25	88	2,4–D 6/20 & 8/20	98	100
32	plow 8/11, 2,4–D 9/25	88	2,4–D 6/20 & silage	89	97
33	plow 8/11, 2,4–D 9/15, cult. 10/15	92	Repeat 1st yr.	99	100
34	plow 8/11, 2,4–D 9/15, cult. 10/15	92	2,4–D 6/20	90	99
35	plow 8/11, 2,4–D 9/15, cult. 10/15	92	2,4–D 6/20 & 8/20	99	98
36	plow 8/11, 2,4–D 9/15, cult. 10/15	92	2,4–D 6/20 & silage	81	100

[a]Oats seeded on all plots April 20; ¾ lb/A of alkanol amine salt of 2,4–D applied on all plots on June 7; plowing with moldboard plow and cultivation with duckfoot field cultivator on dates indicated.

[b]Three-fourths of treatments included corn planted June 5, sprayed with ¾ lb/A of alkanol amine salt of 2,4–D on dates indicated and cultivated 3 times. In other treatments oats was seeded April 20 or Piper sudangrass was seeded June 20 after 2 cultivations. Silage and sudangrass hay were harvested the first week in September and fall plowed.

[c]All plots except 21, 22, 23, 24 repeated the first year's treatment; those four plots grew flax, treated with ¼ lb/A MCPA.

A June application of 2,4–D amine, a plowing with a moldboard plow during early August (one week to 10 days after harvest) and 2 cultivations during September with a duckfoot field cultivator in treatments 17 to 24 killed an average of 88 per cent of the Canada thistle plants and 84 per cent of the perennial sowthistle plants. The substitution of MCPA or 2,4–D ester during June eliminated 85 and 88 per cent of the Canada thistle and 92 and 98 per cent of the sowthistle, respectively.

A June treatment with 2,4–D amine, post-harvest plowing, 2 cultivations in September, and a third cultivation during mid-

October in treatments 25 to 28 eliminated 83 percent of the Canada thistle and 92 per cent of the sowthistle while similar treatments with MCPA reduced the stands 81 and 96 per cent, respectively, indicating that the late fall cultivation did not increase the percentage kill materially when earlier post-harvest cultivations were performed.

Spring spraying and the post-harvest plowing followed with a fall application of ¾ lb/A of 2,4–D amine to the fall rosettes after they emerged on the plowing in treatments 29 to 32, reduced the stands of Canada thistle and sowthistle 88 and 92 per cent, respectively. The same operations plus a mid-October cultivation in treatments 33 to 36 eliminated 92 per cent of each species, indicating that late fall cultivation was not effective when preceded by other fall operations.

Although one experiment contained a moderate infestation of perennial sowthistle when the study was initiated, one year's treatment reduced the stand to the point where it seemed unwise to place any confidence in any subsequent results.

Second year. Treatments 1, 5, 9, 13, 17, 25, 29 and 33 were each a repetition of the first year. The same crop, spraying, plowing and cultivation operations used the first year were repeated the second. Mo. 0–205 oats was used in the second year of the first experiment, but Garry was used in the second. In these 8 treatments, 2,4–D amine was used as the herbicide. In addition, MCPA was used in two treatments and 2,4–D ester was used in one. The stand of Canada thistle was further reduced by all the treatments. In 9 of the 11 treatments the stand was reduced over 95 per cent in 2 years.

Treatment 21 utilized 2 June cultivations, a crop of Piper sudangrass that was harvested for forage during early September and a fall plowing. It increased the percentage of kill from 88 to 99 per cent.

All other treatments included a crop of corn. S.D. 270 was used in the first experiment, but the earlier maturing S.D. 220 was planted in the second. The crop was planted on fall plowing after weed counts had been made during early June. The corn was cultivated lengthwise twice and crosswise once and an over-all treatment of 2,4–D or MCPA was applied, in 12 gallons of spray per acre, during late June one week before the second cultivation. Three-fourths lb/A acid equivalent of an alkanol amine of 2,4–D was applied in the 27 treatments shown in Table 1, the same amount of the diethyl amine of MCPA in 6 other treatments and ½ lb/A of the ethyl ester of 2,4–D in 3 others.

One application of either form of 2,4–D or MCPA in treatments 2, 6, 10, 14, 18, 22, 26, 30 and 34 allowed the Canada thistle stand to become more dense. The average increase in stand for these 12 treatments was 76 per cent.

Spraying corn with 2,4–D or MCPA during late June and again during mid-August as a directed spray with drop nozzles, reduced

the stand of thistles in treatments 3, 7, 11, 15, 19, 23, 27, 31 and 35, an average of 38 per cent beyond the reduction achieved the first year. Nine of the 12 treatments had increased the percentage kill to over 90 per cent in 2 years.

Cutting corn for silage and fall plowing after treatment with 2,4–D or MCPA in June, maintained the gains obtained the previous year in treatments 4, 8, 12, 16, 20, 24, 28, 32 and 36. The 12 treatments reduced the stand an average of 4 per cent.

Third year. Treatments 21 to 24 utilized a crop of Marine flax that was sprayed with ¼ lb/A of MCPA in 12 gallons of spray per acre when the thistles were in the spring rosette stage of growth and the flax was 4 to 6 inches tall. The stubble was fall plowed during early September. Previous treatments had weakened the thistles to the extent that these treatments were able to bring the final count to 97 and 99 per cent elimination at the end of 3 years.

Each other treatment included a repetition of operations used the first year with Garry oats as the crop. Forty of the 48 treatments resulted in 95 to 100 per cent elimination at the end of 3 years.

Crop yields. Low yields were obtained the first two years because of low fertility. The soil is classified as a silty-clay loam belonging to the Estelline series and is located on the second bench from the James River. As a consequence, the soil warms slowly in the spring resulting in slow nitrification. No fertilizer was applied the first two years.

The first year Mo. 0–205 oats sprayed with 2,4–D amine, 2,4–D ester and MCPA amine yielded 19, 18 and 21 bushels per acre, respectively. During the second year 25 inches of precipitation (about 5 inches above the long term mean) fell and the same crop given the same spray treatments yielded 24, 28 and 25 bushels per acre. S.D. 270 corn, which does not mature quite early enough to be planted in June, produced 24, 25 and 26 bushels after one spraying and 25, 24 and 21 bushels after being sprayed twice with the same herbicides.

The rainfall for the third and fourth years was 25 and 15 inches, respectively. Nitrogen was applied as a starter fertilizer for small grain and sidedressing for corn, while a mixed starter fertilizer was used for corn. Garry oats treated with 2,4–D amine, 2,4–D ester and MCPA amine yielded 37, 41 and 42 bushels the third year and 54, 51 and 54 the fourth year. S.D. 220 corn produced 56, 55, and 58 bushels after one spraying and 53, 48, and 48 bushels after being sprayed twice with the same herbicides the third year. These yields are well above the average for the area and indicate that the herbicidal applications had little effect on yield of crop.

Summary. Although most of the treatments eliminated a high percentage of thistles in 3 years, it was apparent that treatments that included a spring spraying and a late summer or fall treatment were superior to those that did not include the late treatment. It appeared that 2,4–D or MCPA applied during the spring pre-

vented seed production, killed some susceptible plants and weakened more resistant plants so that later treatments could deliver the knockout punch.

After having seen some of these practices used in the field, the authors' first choice, from the standpoint of eliminating weeds, is treatment 17. However, it requires 3 consecutive crops of small grain and leaves the land bare over winter. Although treatments 29 and 33 appear to be equally effective, they are too dependent on the effectiveness of the herbicides and are therefore less effective than treatment 17 when employed on populations containing a high percentage of plants of resistant strains. For corn growing areas, treatments 19 and 23 are the most practical treatments tested and were equally effective. However, they too are largely dependent on the effectiveness of the 2,4–D. Treatment 21 is an effective treatment for use in flax growing areas. It utilized 2,4–D and MCPA during 2 years and allows the use of cultivation during 3 years. It does, however, include a crop of sudan grass that may be of little value in many areas.

The crops were not injured materially. However, it is known that Garry and Mo. 0–205 are two of the more tolerant oats varieties[4] and Marine flax and S.D. 220 corn are also relatively tolerant varieties.

Perennial crops, cultivation and chemicals.

One 3-year experiment, in which various combinations of alfalfa or bromegrass, intensive cultivation and 2,4–D or MCPA were compared, was initiated during the spring of 1955. It included 36 treatments in 2 replications. The area was heavily infested with Canada thistle and moderately infested with perennial sowthistle. The number of plants of each species was counted annually on the same 4 one-square-yard areas of each plot during the first week in June. Counts made in June 1955 were made before any spraying or cultivating was done, counts made in 1956 and 1957 were made to evaluate the previous year's treatment, and counts in 1958 were made the spring after all treatments had been completed. An identical experiment was initiated during 1956 and completed during June 1959. This second area was moderately infested with Canada thistle and sparsely infested with sowthistle. It was felt that the sparse stand did not yield reliable data; therefore, sowthistle data from this experiment are not reported. Twenty of the treatments and the percentage of Canada thistle killed by each are given in Table 2.

Treatments 1 to 8 were cultivated 4 times at 3-week intervals and seeded to alfalfa or bromegrass alone or in a mixture during mid-August. The use of a duckfoot cultivator and one-way disk each eliminated 88 per cent of the Canada thistle and 85 per cent of the perennial sowthistle. During the second year a crop of alfalfa

[4]Derscheid, Lyle A and Dirks, V. A. Unpublished data from trials in which new small grain varieties were tested for tolerance to 2,4–D at several stages of growth during 1955–58.

Table 2. Percentage of Canada thistle eliminated by use of perennial forage crops, cultivation and 2,4–D (mean of two 3-year experiments).

Trt. No.	First year		Treatment[b] second and third years	Percent kill	
	Treatment[a]	Pct. kill		Second year	Third year
1	Cult., alfalfa	88	Harvest hay	98	100
2	Cult., alf-brome	88	Harvest hay	100	100
3	Cult., brome	88	Harvest hay	93	100
4	Cult., brome	88	2,4–D 6/7	94	100
5	Cult., brome	88	2,4–D 6/25	97	98
6	Cult., brome	88	2,4–D 9/1	99	100
7	Cult., brome	88	2,4–D 6/7 & 9/1	99	100
8	Cult., brome	88	2,4–D 6/25 & 9/1	97	100
9	Alfalfa, clip 6/20	62	Harvest hay	89	100
10	Alf-brome, clip 6/20	71	Harvest hay	92	100
11	Bromegrass, clip 6/20	68	Harvest hay	92	100
12	Alfalfa, ¼ lb 6/7	83	Harvest hay	71	100
13	Alf-brome, ¼ lb 6/7	70	Harvest hay	98	100
14	Bromegrass, ½ lb 6/7	81	Harvest hay	98	97
15	Brome, ¼ lb 6/7	81	2,4–D 6/7	89	96
16	Brome, ½ lb 6/25	23	2,4–D 6/25	67	98
17	Brome, ½ lb 9/1	23	2,4–D 9/1	50	95
18	Brome, ¼ lb 6/7 & 9/1	72	2,4–D 6/7 & 9/1	94	94
19	Brome, ¼ lb 6/7 & 9/1	72	2,4–D 6/25	59	95
20	Brome, ½ lb 6/25 & 9/1	72	2,4–D 6/25 & 9/1	94	95

[a]Cult. refers to 4 cultivations performed at 3-week intervals between June 14 and August 17; ¼ lb and ½ lb refer to amounts per acre of alkanol amine salt of 2,4–D applied at dates indicated—June 7, thistles in rosette; June 25, thistles in bud; September 1, thistles in fall rosette.

[b]Alkanol amine salt of 2,4–D applied at ¾ lb/A on dates indicated; two crops of hay harvested from plots containing alfalfa and one crop from bromegrass plots.

increased the per cent kill to 98 for Canada thistle and 95 for sowthistle. A crop of alfalfa-bromegrass killed all the Canada thistle and 94 per cent of the sowthistle. A crop of bromegrass was almost as effective for both species. By the end of the third year all had completely eliminated both species. A crop of bromegrass sprayed in treatments 4 to 8 with ¾ lb/A of an alkanol amine of 2,4–D once or twice during the second year when the thistles were in spring rosette, bud or fall rosette stages of growth, eliminated 94 to 99 per cent of each species by the end of the second year and 98 to 100 per cent by the end of the third year. When the 2,4–D was replaced with the same amount of diethyl amine of MCPA in 4 treatments or ethyl ester of 2,4–D in three treatments, very similar results were obtained. These results indicate that the first season of cultivation was very helpful in eliminating the thistles but that the 2,4–D or MCPA were not.

Treatments 9 to 14 included the same crops used in treatments 1 to 3, but were planted with an oats companion crop during the spring of the first year without the benefit of 4 cultivations. Clipping in treatments 9 to 11 during early June prevented thistle seed production and killed 62 to 71 per cent of Canada thistle but allowed an increase in the stand of sowthistle. In treatments 12 to 14, ¼ lb/A of alkanol amine of 2,4–D was applied in lieu of the clipping, resulting in 70 to 83 per cent elimination of Canada thistle and 40 to 50 per cent kill of sowthistle. The alfalfa was

injured by the 2,4–D and allowed the stand of thistles to increase the next year. However, all the other 5 treatments eliminated more thistles the second year. By the end of the third year almost complete elimination had been obtained by each of these 6 treatments.

Bromegrass was sprayed, in treatments 15 to 20, with ½ lb/A of an alkanol amine of 2,4–D at various stages or combinations of stages of growth. Better kills obtained by treatments 15 and 18 to 20 the first year indicated that spraying Canada thistle in the spring rosette stage of growth during early June or two later sprayings were the most effective treatments. The same trend existed to a lesser degree after spraying at the same growth stages with a higher rate the second year. This trend did not exist for sowthistle nor for either species when MCPA or diethyl ester of 2,4–D was used. After 3 years of repeated sprayings at the same stages of growth, all treatments eliminated a high percentage of thistles.

Summary. All treatments were effective, indicating that good stands of alfalfa and/or bromegrass eliminate a high percentage of both Canada thistle and perennial sowthistle in 3 years without the aid of cultivation, 2,4–D or MCPA. However, 3 years were required to give the same results obtained in 2 years when cultivation was used prior to late summer seeding of the crop.

Soil sterilants.

One experiment was conducted to determine the optimum rate of application of numerous soil sterilants for the elimination of small patches of thistles. The chemicals were applied at several rates at two dates—late July and mid-September of 1955. Shortly after treatment the plots were checked to observe the speed of action of each chemical. The following year the effect of each treatment on the weed was noted. During 1957 and 1958 the plots were plowed and seeded to oats to determine the length of time that the chemicals would inhibit small grain production.

The chemicals used and the minimum rate that gave 95 to 99 per cent elimination are given in Table 3. All chemicals were more effective when applied during September. The lower rate was effective at that date but the higher rate was usually needed for the July application.

Other herbicides.

In several experiments numerous herbicides were screened for possible use in controlling thistles. During 1955 the area for one experiment was seeded to Garry oats April 23. Thistle stands were counted June 7 and herbicides were applied in 40 gal/A of spray solution June 9 when weeds were in spring rosette stage of growth and grain in 5-leaf stage. One-half of each 1-rod by 3-rod plot was plowed August 17. All chemicals had been applied at rates of 1 and 4 lb/A acid equivalent or active ingredient. The lower rate was unsatisfactory for all herbicides, but the higher rates of some of them appeared promising and the late summer plowing appeared to have improved the results. Four pounds of 2–chloro–4,6–bis

Table 3. The minimum rate of soil sterilants required to eliminate 95 percent of Canada thistle and perennial sowthistle and years of residual effect.

Herbicide	Lb per sq rd[a]	Residual effect, years
Borax compounds		
Concentrated Boracu[b]	12–15	3+
Polybor[c]	12–15	3+
Chlorates		
Sodium chlorate	5	2–3
Atlacide[d]	6–8	2–3
Borate-chlorate mixtures		
Chlorax[e]	10–12	3+
Polybor-chlorate[f]	10–12	2–3
Borate–2,4-D mixture		
DB Granular[g]	5–6	2
Borate–chlorate–monuron mixtures		
Chlorea[h]	6–8	3+
Ureabor[i]	7.5[k]	3+
AMS[j]	4–6	1
Erbon	½–1	3
Substituted urea compounds		
monuron	1/3[k]	3+
diuron	1/3[k]	3+
fenuron	1/3	3+

[a]Amount of active ingredient for substituted ureas and erbon and amount of product for others.
[b]Sodium borate ore (61.5% boron trioxide).
[c]Disodium octoborate tetrahydrate 98% (64% boron trioxide).
[d]Sodium chlorate 58%.
[e]Sodium metaborate 58%, sodium chlorate 40%.
[f]Disodium octoborate tetrahydrate 73% (49% boron trioxide) sodium chlorate 25%.
[g]Disodium tetraborate pentahydrate 55%, disodium tetraborate decahydrate 30.8% (39.2% boron trioxide), 2,4-D 7.5%.
[h]Sodium metaborate 54%, sodium chlorate 40%, monuron 1%.
[i]Disodium tetraborate pentahydrate 63.2%, disodium tetraborate decahydrate 30.8% (41.5% boron trioxide), monuron 4%.
[j]Ammonium sulfamate 80%.
[k]Highest rate used, but did not give 95% elimination.

(diethylamino)–*s*–triazine (chlorazine) and three polychlorobenzoic acid compounds were quite effective. One benzoic acid compound was largely composed of trichloro– and tetrachloro– isomers, another was largely tetrachloro–isomers and the third was predominantly the sodium salt of 2,3,6–trichlorobenzoic acid (2,3,6–TBA). Ester forms of 2,4–dichloropropionic acid (2,4–DP) and 2–methyl–4–chlorophenoxypropionic acid (MCPP) appeared to be superior to amine forms. Application of 4 lb/A of 3–amino–1,2,4–triazole (amitrole) and 4–(2,4–dichlorophenoxy)butyric acid [4–(2,4–DB)] gave good top kill but allowed regrowth.

During 1956 amitrole at rates of 4, 6, and 8 lb/A and 4–(2,4–DB) at rates of ½, 1 and 2 lb/A were applied to thistles in the spring rosette on June 4. By mid-July the tops of amitrole-treated plants were black and appeared to be dead; however, the roots were not injured and 75 to 80 per cent of the plants recovered. The 2 lb/A rate of 4–(2,4–DB) produced noticeable effects on Canada thistles. It caused stunting and prevented seed production but reduced the stand only 18 per cent.

Subsequent experiments were conducted during 1957 and 1958

in which amitrole was applied at rates of 2, 4, and 6 lb/A in 12 gallons of spray per acre to Canada thistle at 2 stages of growth—spring rosette and bud, while 4–(2,4–DB) was applied at rates of 1, 2, and 4 lb/A to Canada thistles in spring rosette stage of growth.

Amitrole applied to the rosette stage of growth caused the thistle tops to wither, but did not kill more than 25 per cent of the plants. When applied to thistles in bud, it acted very slowly. The plants drooped and turned yellow in about 10 days, but sometimes appeared to recover by the end of 3 or 4 weeks. However, they did not produce seed and were dead at the end of 6 weeks. Rates of 4 and 6 lb/A generally reduced stands 90 to 95 per cent. The action of 4–(2,4–DB) was much faster. Although Canada thistle plants continued to grow slowly, all rates caused tops to droop and the 4 lb/A rate sometimes caused the stems to turn black. The lower rates caused more stunting of growth than ½ lb/A of 2,4–D. Rates of 2 and 4 lb/A consistently prevented the production of seed, but did not reduce stands more than one-third.

Summary. Although several herbicides appeared promising only amitrole and 4–(2,4–DB) were tested extensively. The results indicate that amitrole at a rate of 4 lb/A will kill 90 to 95 per cent of Canada thistle plants if applied at the bud stage of growth in as little as 12 gallons of spray per acre. The 4–(2,4–DB), on the other hand, appears to be useful in checking growth and preventing seed production. It may be useful for aiding in the establishment of legumes in Canada thistle infested areas.

SUMMARY AND CONCLUSIONS

On a 25-acre tract of Canada thistle and perennial sowthistle, several experiments were conducted during 1955 to 1958 to study control methods. Included were two 1-year experiments comparing duckfoot field cultivator, one-way disk, and tandem disk harrow at various intervals for intensive cultivation; two 3-year experiments utilizing 48 combinations of annual crops, cultivation and 2,4–D; and two 3-year trials using 36 combinations of perennial forage crops, cultivation and 2,4–D. Each experiment was replicated in a randomized block design with plots 1 rod by 3 rods. Weed counts were made on 4 areas of 1 square yard in each plot during early June each year, 1955–1959, to determine original stand and to evaluate each year's treatment.

One experiment comparing several commercially available soil sterilants at several rates, each on 2 dates, was conducted in duplicate 9-foot by 15-foot (½ square rod) plots. Numerous other herbicides were screened for possible use in the elimination of large infestations of thistles in duplicate 1-rod by 3-rod plots. Amitrole and 4–(2,4–DB) were tested more extensively.

The following conclusions can be drawn:

1. Canada thistle and perennial sowthistle react to 2,4–D and MCPA. Ester and amine forms of 2,4–D are equally effective

for sowthistle, while both forms and MCPA are equal for Canada thistle.

2. Both herbicides prevent seed production, kill susceptible plants and weaken resistant plants so that later treatments can deliver the knockout punch.
3. While growing annual crops, the knockout punch can be delivered by late summer spraying, post-harvest cultivation, a combination of late cultivation and spraying or a strongly competitive crop the next year. Spraying is less effective if the population contains plants belonging to strains that are resistant to the chemicals.
4. A season of intensive cultivation followed by a late summer seeded crop of alfalfa and/or bromegrass eliminates 95 to 100 percent of the thistles in 2 years. Without the intensive cultivation, 3 years are required to give similar results. When good grass stands are maintained, the application of 2,4–D or MCPA may not improve results materially.
5. Several soil sterilants can be used to eliminate small patches of thistles.
6. Amitrole is effective for reducing Canada thistle stands when applied to the bud stage of growth.
7. 4–(2,4–DB) is effective for checking growth and preventing seed production by Canada thistle when applied to the spring rosette stage of growth. It may be useful in establishing legume stands in Canada thistle infestations.
8. Intensive cultivation with a duckfoot field cultivator or a one-way disk to a 4-inch depth at 4-week intervals (5 operations), or double-coverage with a tandem disk harrow at 2-week intervals (16 operations) eliminates over 99 per cent of both thistle species in one year.
9. Canada thistle and perennial sowthistle are much less difficult to eliminate than leafy spurge or Russian knapweed and slightly less difficult than field bindweed.

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Acetylenic Derivatives as Herbicides[1]

J. K. Leasure and M. J. Josephs[2]

Introduction

The materials known as herbicides represent many different chemical groups. Well-known herbicides include aromatic hydrocarbons, halo-aryloxy organic acids, substituted carbamates, substituted ureas, sulfamates, cyanates, substituted phenols, symmetrical triazines, and many others.

Despite the large number of widely different chemicals used for weed control, only one of the commercially available herbicides contains an acetylene group: barban (4–chloro 2–butynyl *N*–3–chlorophenylcarbamate). A thorough search of the literature reveals only a very small number of reference to such compounds. Other than barban, the nearest approach in commercially available herbicides is allyl alcohol (CH_2=$CHCH_2OH$) which is used in a limited way for sterilizing tobacco seed beds, other areas of similar use and for controlling aquatic weeds. Other than the recent references to barban, there have been no references to acetylenic compounds as herbicides in Agronomy Journal, Weeds, the Proceedings of the various weed conferences, or any of the standard herbicide textbooks.

The Chemical Biological Coordination Center Positive Data Series, Publication 384 of the National Academy of Science–National Research Council listed 1066 compounds out of 6536 tested as having some biological activity. Two "ethynyl" compounds were included in this list. They were 1–ethynylcyclohexanol and 1–ethynyl–2–methylcyclohexanol. The activity of these materials, as reported in these publications is summarized:

1–ethynylcyclohexanol:

Test method	Comparison to untreated check
Lanolin paste on bean stem	shorter internodes
Lanolin paste on cucumber	shorter internodes
Lanolin paste on sunflower	growth somewhat inhibited—about 5%

1–ethynyl–2–methyl–cyclohexanol:

Red kidney bean seedlings dipped	no effect
Cucumber germination *in vitro*	no roots developed

In these tests, there was no report of tissue kill, tissue proliferation, or epinasty. Although test procedures in which seeds were planted in treated soil were used as standard parts of some Chemical Biological Coordination Center series tests, such tests were not used

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[2]Agricultural Chemicals Research Department, The Dow Chemical Company, Midland, Michigan.

with these two compounds; yet it is principally in pre-emergence soil application that the activity of these ethynyl compounds is most evident.

RESULTS AND DISCUSSION

Some acetylenic derivatives have shown sufficient activity in biological screening tests to warrant an investigation of their herbicidal activity. The results have been extremely interesting in that their activity would not have been predicted on the basis of generally accepted structure-activity relationships.

These compounds have shown an activity pattern which can be summarized as follows. They were:

1. Extremely active when used in pre-emergence applications.
2. More active on broad-leaved species than on grasses.
3. Almost completely inactive when used in post-emergence foliage applications.
4. Very effective when applied to the root zone of growing plants at all stages of development.
5. Moderately persistent in the soil.

Within the group of acetylenic compounds showing this general pattern of plant response, there were considerable differences in the degreee of activity.

One of the most active compounds of this group was 1–ethynyl cyclohexanol (Figure 1) which fortunately was both easy to work with and readily available. It was used therefore as a starting material to prepare many other compounds having different biological activities.

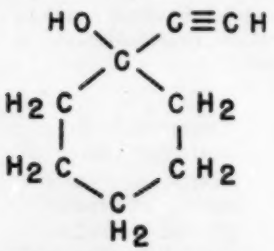

Figure 1. The chemical structure of 1–ethynylcyclohexanol.

Compounds such as isopropylcyclohexanol were inactive as herbicides, suggesting that the —C≡C— group is required for significant herbicidal activity. Furthermore, the low activity of 1–ethynylcyclopentanol indicated the probable importance of the spatial configuration around the —C≡C— group. This was perhaps confirmed by the observation that, whereas 1–(1–propynyl)–cyclohexanol was active, 1–(2–propynyl)–cyclohexanol was inactive.

It was found that ethers and esters of 1–ethynylcyclohexanol are also active, the ethanol ether, the propanol ether, the tris-phosphite, the acetate ester, and the ethyl carbonate all showing activity equivalent to that of the parent material. Other substitutions such as the amine, the chloride, and the thiol resulted in compounds having little or no herbicidal activity.

The herbicidal activity of 1–ethynylcyclohexanol is typical of the active compounds in this group. Pre-emergence applications at rates

of 20/lb A in the greenhouse gave 100 percent control of such species as radish, Japanese millet, wild oats, corn, wheat, soybeans, cotton, German millet, Johnsongrass, mustard, sugarbeets, crabgrass, and morning glory. At rates of 5 lb/A, some of the large-seeded grasses such as corn, wild oats, and Johnsongrass were controlled only about 95% although 100% control of the other species was obtained.

In the field, somewhat higher rates were required for equivalent control. With decreasing rates, or with compounds having lesser activity, complete control of broadleaf species was maintained, although grasses grew normally. This same pattern of selective activity was noted when the persistence of these materials in the soil was studied.

In a greenhouse persistence test, cotton, radish, Japanese millet and wild oats were planted in six-inch diameter crocks, which were then treated with 1–ethynylcyclohexanol at a rate of 20 lb/A. After three weeks, the pots were replanted but were given no additional chemical treatment. Replanting at three-week intervals was continued until practical control (less than 50% on all test species) was no longer obtained from the residual chemical in the soil. Results are presented in Table 1.

Table 1. Persistence and degree of herbicidal activity of 1–ethynylcyclohexanol as measured by the response of successive plantings of susceptible species. A single original application was made at 20 pounds per acre.

Time in weeks after treatment for successive plantings	Percent kill			
	Cotton	Radish	Japanese millet	Wild oats
3	100	100	100	100
6	100	100	90	80
9	100	100	30	20
12	98	99	0	0
15	95	98	0	0
18	60	98	0	0
21	60	70	0	0
24	70	60	0	0
27	20	20	0	0

Field results have indicated that optimum activity is in part dependent on soil moisture. In one field test in Mississippi, excellent control of crabgrass and *Brachiaria* was obtained when approximately one inch of rain fell immediately after application, but at two nearby locations which did not receive rain, poor control was obtained.

In Michigan, control of a wide variety of broadleaved and grassy seedlings has been obtained for two to three months following application, apparently regardless of rainfall.

Some of these acetylenic compounds have shown enough activity as pre-emergence herbicides in greenhouse and field tests to appear to be of practical utility as herbicides. The physiological activity of these materials will be the subject of further investigations.

Confining Fumigants in the Soil with Surface Seals[1]

STANLEY J. PIECZARKA[2] and G. F. WARREN[3]

TREATMENT of soil with fumigants to kill dormant weed seeds is a valuable practice but control in the surface one or two inches is often poor. This is because the fumigant vapors diffuse rapidly out of the soil into the atmosphere before building up a lethal concentration near the surface. Improved weed control has been reported by proper confinement of fumigant vapors in the soil with impervious seals (2, 3, 5, 6, 9). Water seals have been advocated by some workers as a satisfactory substitute for impervious covers (1, 4, 7). However, only limited experimental data are available comparing soil fumigation results with different methods of sealing the soil surface.

Godfrey (6) was one of the first to recognize the need of an impervious cover to confine fumigant vapors in the soil. From his experiments with chloropicrin came the development of tar-coated and glue-coated paper for this purpose. In later years polyethylene films replaced coated papers and a large number of workers reported improved pest control with the use of this material as a seal (3, 4, 9). However, the use of polyethylene film is restricted to small areas because of problems in applying and reclaiming the film. The potential for fumigation of extensive crop areas for control of weed seeds and soil pathogens would be much greater if a low-cost surface seal could be applied as a spray or by some other simple method.

Studies were undertaken in 1959 to compare the weed control obtained with drench applications of fumigants when a water seal and a polyethylene seal were used. A procedure also was developed that could be used to evaluate possible materials to be sprayed on the soil after fumigation to confine the vapors. The effectiveness of several materials was compared with polyethylene film.

MATERIALS AND METHODS

Seed bed experiment. A pile of rotted, shredded manure was fumigated in March with methyl bromide at the rate of 2 pounds per 100 cubic feet under polyethylene. One week later this manure was placed in 4 inch deep veneer bands in a cold frame in randomized groups 3 × 6 feet in size. In the rest of the area, unfumigated manure was placed in the bands so that drenches could be applied. SMDC (sodium *N*–methyldithocarbamate dihydrate, Vapam), allyl alcohol, and emulsifiable 1,3–dichloropropene were applied at 400 and 800 lb/A of active material. The concentrated fumigant was diluted in 2 gallons of water which was then sprinkled over each

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[2]Formerly Research Assistant. Present Address: Ferry–Morse Seed Co., Salinas, California.

[3]Professor of Horticulture, Purdue University, Lafayette, Indiana.

plot. Approximately 15 gallons of water was applied per plot after this initial application to wet through the manure in the bands and 2 to 3 inches into the soil below. The water applied in the drench served as the water seal and a 4 mil polyethylene film was applied as the other seal. The experiment had two replicates in a completely randomized block design. The treatments were applied March 24; the soil temperature was 50°F.

In the application of the fumigants, contamination between plots was prevented by enclosing the area to be fumigated with tin sheets 12 inches high. The polyethylene covers were removed in five days and muskmelon seeds of the variety Queen of Colorado were planted 22 days after treatment. Weed counts were made 20 days later in the center portion of each plot. The weeds were grouped as broadleaf and grasses. The broadleaf weeds included rough pigweed (*Amaranthus retroflexus*), purslane (*Portulaca oleracea*), carpetweed (*Mollugo verticillata*) and some others. Grasses included crabgrass (*Digitaria sp.*), foxtail (*Setaria sp.*), and barnyard grass (*Echinochloa crus-galli*). A leaf measurement of the melon seedlings was made by measuring in centimeters the length at the main vein of the first true leaf. This was done because large differences were noticed in the size of the plants in the different plots.

Soil surface sealing sprays. A number of water soluble or emulsifiable materials were obtained with properties which might provide a satisfactory seal on the soil surface. Before these could be screened a method had to be developed to evaluate their sealing capabilities. A bio-assay of dormant inbibed tomato seeds was used (8). Twenty-five tomato seeds were placed in a piece of cheese cloth of which the edges were stapled together and trimmed. These were then moistened and held for one week at 48°F. before being used. Metal cans, 6½ inches deep and 4¼ inches in diameter with a capacity of 1500 ml, were used in this experiment. A ½ inch hole was drilled in the side one inch up from the bottom through which the fumigant could be added. A wire screen of ⅛ inch mesh was cut to fit the inside of the container. This screen was elevated from the bottom of the container by 1½ inch long brass screws. A Princeton fine sand was placed in the container up to ½ inch from the top. On this layer were placed 4 samples of 25 dormant imbibed tomato seeds. The containers were then filled with soil and the surface leveled as smoothly as possible. The container then had 5 inches of soil with a 1½ inch air space in the bottom. This allowed the fumigant to vaporize in the air space and pass uniformly through the soil to the surface. A sealing material was sprayed on the surface and the fumigant introduced through the side of the container and the hole was then plugged with a rubber stopper. All experiments were conducted at 48°F. After treatment the tomato seeds were removed from the soil and placed on filter paper at a temperature range of 75–80°F. for germination from which the percent kill was calculated.

From preliminary experiments it was found that a rate of 200

lambda per container of 1,3–dichloropropene for a period of 24 hours with a 4 mil polyethylene seal, produced 100 percent kill. With no seal, approximately 20 percent kill resulted. Therefore, this concentration and time of exposure were used throughout these studies. If the seals produced any effect, the percent kill would have to be more than 20 percent.

The treatments applied to the soil surface were the following: Saran Latex F–122A15 and F–122A20 used as a concentrate, containing 52 percent solids and also diluted to 10 percent solids (Dow Chemical Co.); Dow Latex 512R, 512K, and 762W diluted to 10 percent solids (Dow Chemical Co.); Vinsol Emulsion diluted to 10 percent solids (Hercules Powder Co.); Polyox WSR 301, made up as a 0.125 percent solution (Union Carbide Chemical Co.); Plyac, as a concentrate (General Chemical Co.); Goodrite Latex VL–600, as a concentrate (B. F. Goodrich Chemical Co.); four mil polyethylene film; one and one half mil polyethylene film; polyethylene coated paper; check treated with fumigant but no seal; check with no fumigant.

The solutions were sprayed on the soil surface at a pressure of 30 psi, using a paint sprayer that had a fan type nozzle. The rates used were 500 and 1000 gallons per acre. The polyethylene and paper films used were sealed to the surface of the container with calking compound. Each treatment was replicated five times.

RESULTS

Seed-bed experiment. The polyethylene seal greatly reduced the number of weeds per square foot compared to a water seal (Table 1). In fact, a polyethylene seal at the 400 lb/A rate of fumigant resulted in fewer weeds per square foot than the 800 lb/A rate with only a water seal.

All fumigants produced good weed control when a polyethylene seal was used at the proper rate with the exception of allyl alcohol, which failed to give good grass control. As indicated by the leaf index data in Table 1, some of the treatments reduced the growth of the melon plants. This may have been due to insufficient aeration after fumigation.

Soil surface sealing sprays. Table 2 presents data that show the sealing capabilities of materials sprayed on the soil surface in an attempt to confine the vapors of 1,3–dichloropropene in the soil. When the fumigant was introduced into the bottom of the container and no seal applied, an average of 22 percent kill resulted. When either a 4 mil or 1½ mil polyethylene seal was applied, 100 percent kill resulted. Latex VL–600 approached polyethylene in effectiveness. Other materials, which showed promise, were Plyac and Vinsol Emulsion. Most of the other materials produced little increase in percent kill of tomato seeds when compared to the check.

The need of an impervious seal to confine the fumigant vapors was also demonstrated. Where no seal was used, only a small per-

centage of the tomato seeds were killed. A thin polyethylene seal gave 100 percent control at the soil surface.

Table 1. Effect of seedbed fumigation on weed control and growth of muskmelons.

Fumigant	Seal	Pounds per acre	Weeds per square foot		Leaf index* cm
			Broadleaf	Grasses	
Check	—	—	14.9	106.8	6.0
1,3-Dichloropropene	Water seal	400	14.1	110.5	5.7
		800	18.6	106.1	5.4
	Polyethylene	400	9.2**	54.2**	5.4
		800	2.0**	7.9**	3.9**
SMDC	Water seal	400	17.8	98.2	5.0**
		800	8.5**	53.7**	4.5**
	Polyethylene	400	2.9**	2.4**	5.2*
		800	0.9**	0.9**	6.3
Allyl alcohol	Water seal	400	8.5**	73.9	6.0
		800	5.7**	45.6**	5.9
	Polyethylene	400	7.0**	38.8**	5.4
		800	2.0**	22.0**	5.9
Methyl bromide	Polyethylene	860	1.1**	2.0**	4.4**

*Leaf index obtained by measuring in centimeters the length at the main vein of the first true leaf. Index is the mean of ten measurements.

* and ** Significant at 5 percent and 1 percent level respectively. Data on weed counts analyzed by the transformation $\sqrt{x} + .5$.

Table 2. Effect of soil surface seals on kill of tomato seeds fumigated with 1,3-dichloropropene.

Material	Percent solids in sealing spray	Rate of sealing spray used gal/A		
		0	500	1000
		Percent kill		
Check-fumigated		22		
Saran Latex F-122A15	52		27	42
Saran Latex F-122A15	10		23	31
Saran Latex F-122A20	52		34	27
Saran Latex F-122A20	10		25	22
Dow Latex 512R	10		29	28
Dow Latex 512K	10		27	42
Dow Latex 762W	10		23	50
Vinsol Emulsion	10		55	67
Polyox WSR301	0.125		50	55
Plyac	Concentrate		50	84
Latex VL-600	Concentrate		91	95
Polyethylene, 4 mil		100		
Polyethylene, 1½ mil		100		
Polyethylene coated paper		97		

DISCUSSION

The results from the seed-bed experiment indicate that better weed control can be obtained with one-half the amount of fumigant when sealed with polyethylene than when only a water seal is applied. Wilson (9) found that a polyethylene seal greatly improved the weed control obtained with SMDC.

In sealing the soil surface it is apparent from the data presented in Table 2 that a thin film is adequate. The polyethylene on the coated paper, which produced 97 percent kill of tomato seeds, was less than 0.005 of an inch in thickness. What is needed, then, is a material that can form a very thin film or successfully block the

pore spaces on the soil surface. In this experiment it was found that the materials which resulted in the higher percentage kills actually cemented the soil particles together to a depth of $^1/_{16}$ to $^1/_8$ inch.

How the seal would behave under different environmental conditions must also be determined. In this experiment the soil surface was wet, the humidity was high, a breeze was passing over the soil surface from the cooling unit, the room in which the experiment was conducted was dark and the soil surface was smooth and continuous. What the sealing potential would be on a dry surface, exposed to light, on different soil types and with different fumigants must be determined for each material that shows promise. A material must perform satisfactorily under a wide range of conditions or it will not be acceptable.

SUMMARY

When soil fumigants were applied as drenches, a polyethylene seal over the plots produced greater weed control than a water seal only. One half as much fumigant was needed to give the same degree of control when the soil surface was sealed with polyethylene as when only a water seal was used.

SMDC at 400 lb/A and 1,3–dichloropropene at 800 lb/A produced good weed control when a polyethylene seal was used. Allyl alcohol controlled broadleaf weeds but failed to give good grass control.

Spraying certain plastic-like materials on the soil surface to confine fumigant vapors was found to give control of dormant seeds in the surface layer nearly comparable to a polyetheylene film. A technique for screening such materials is described.

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Photochemical Degradation of Diuron and Monuron[1]

L. W. Weldon and F. L. Timmons[2]

Considerable attention has been given during recent years to the fate of herbicides sprayed onto soil surfaces. The effect of light upon herbicides also has been studied extensively. Payne and Fults by means of a biological test found that the potency of 2,4–D was increased by exposure to ultraviolet light (7). Hansen and Buchholtz found that when a solution containing 2,4–D and riboflavin was exposed to light the activity of 2,4–D was reduced (5). They tentatively identified the breakdown product as 2,4–dichlorophenol. Later Bell positively identified it (1).

Hill et al. found that 83 percent of the 3–(*p*–chlorophenyl)–1,1–dimethylurea (monuron) was lost when exposed to sunlight for 48 days (6). Birk found that photodecomposition was a factor in the disappearance of monuron (2). Woodford concluded that photodecomposition is of practical importance only in areas where little rain occurs and the herbicides remain on the soil surface for prolonged periods (9).

It was shown by Dorschner and Buchholtz and others that spectrophotometric analysis of herbicides is a rapid quantitative technique (3).

3–(3,4–dichlorophenyl)–1,1–dimethylurea (diuron) is used in Wyoming for the control of annual weeds in alfalfa (8). The applications are made in the spring, and often precipitation does not occur for several weeks. Because of the absence of moisture including dew, there are optimum conditions for photochemical reactions.

The objectives of the experiment were to determine (1) the effect of a controlled light source upon monuron and diuron and (2) the biological activity of any changed material.

Methods and Materials

Samples of recrystallized diuron or monuron were dissolved in 95 percent ethyl alcohol for spectrophotometric determinations. A Beckman DK–2 automatic-differential-recording spectrophotometer was used to make these determinations. The instrument was allowed to scan from 360 mμ to 215 mμ in two minutes using a photomultiplier setting of 20X. Either diuron or monuron at 10 ppm gave an excellent curve in the ultraviolet portion of the spectrum when plotted as percent transmittance. Because the solvent absorbed light below 215 mμ, determinations below that point could not be made.

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[2]Research Agronomists, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture.

The light source for the irradiation treatment was an 85–watt mercury vapor lamp. A conical-shaped reflector was made from special light-reflecting aluminum. The bottom edge of the reflector was located 8 in. above the irradiated material and the reflected light should have been very similar to the emitted light. The following is a listing of the radiant energy in watts for each indicated wavelength emitted by the lamp (4):

Wavelength region and band—A	Watts
Far ultraviolet:	
2200–2300	.02
2500–2600	.07
2600–2700	.59
2700–2800	.05
Middle ultraviolet:	
2800–2900	.69
2900–3000	.64
3000–3100	.75
3100–3200	1.62
Near ultraviolet:	
3200–3300	.32
3300–3400	.45
3400–3500	.21
3500–3600	.21
3600–3700	3.24
3700–3800	.25
3800–4000	.39
Visible:	
4000–4100	1.07
4100–4300	.41
4300–4400	1.93
4400–5400	.83
5400–5500	2.24
5500–5700	.29
5700–5800	1.18
5800–7600	.98

Ten ml of 95 percent ethyl alcohol containing 10 ppm diuron or monuron were pipetted into a petri dish. The solvent was then allowed to evaporate, leaving the chemical. The petri dishes were then placed under the light for the desired period. Samples of both monuron and diuron were exposed to the lamp for 0, 2, 8, and 28 hours. The samples exposed to ultraviolet light for shorter periods were exposed to air at room temperature during the remainder of 28 hours. A second series of dishes was placed in the dark for 28 hours. After treatment 10 ml of 95 percent ethyl alcohol were added to each petri dish to redissolve the chemical. Samples from the redissolved solutions were then placed in the spectrophotometer for the spectroscopic determinations. All treatments were carried out in duplicate.

The effect that exposure to the ultraviolet light would have upon the biological activity of monuron and diuron was determined by

dissolving known amounts in 95 percent ethyl alcohol and placing the solutions in petri dishes. Concentrations were calculated so that the solution in one petri dish when used to treat one plastic 4-in. pot gave a rate of ½ or 2 lb/A of surface area. The solvent was allowed to evaporate, and the dishes containing chemical were

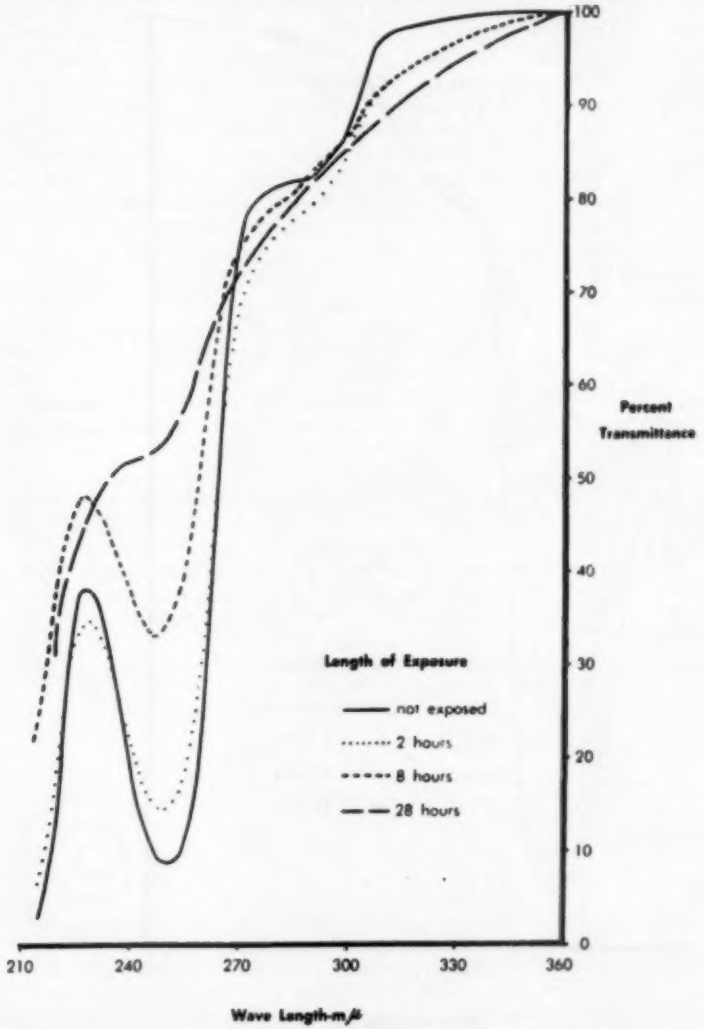

Figure 1. Absorption spectra of diuron after various periods of illumination with an ultraviolet light source.

exposed to the light source for 28 hours. Another series was set in the dark at the same time. At the end of the treatment an excess of ethyl alcohol was added to each dish to redissolve the chemical. No undissolved residue was left. The contents of each petri dish were then poured evenly onto the soil in a 4-in. pot. The alcohol was

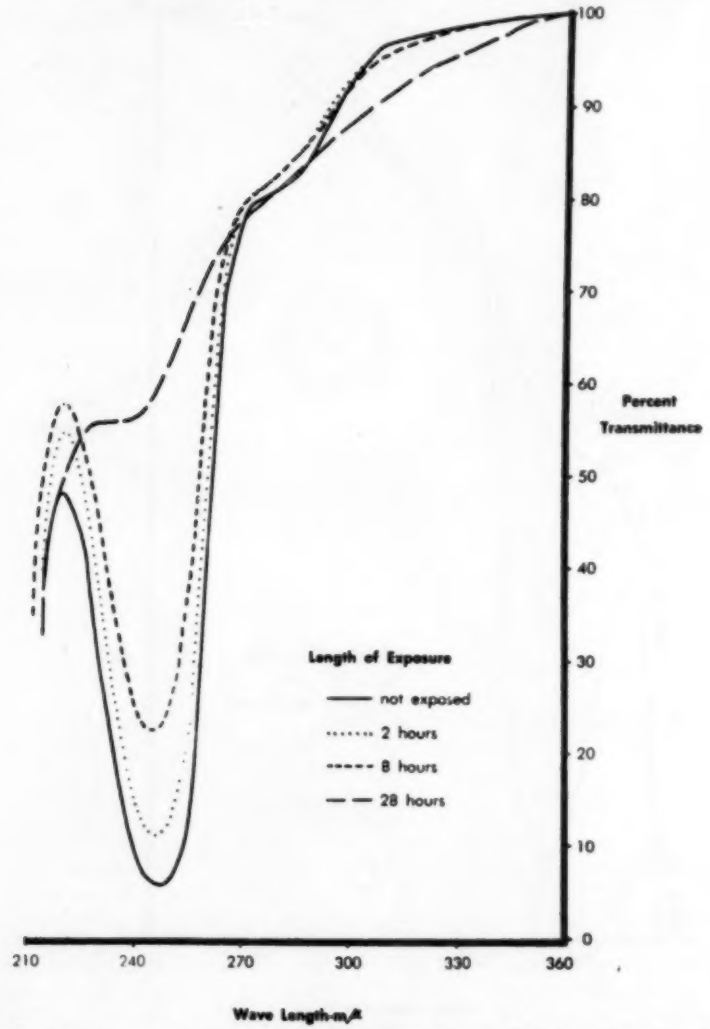

Figure 2. Absorption spectra of monuron after various periods of illumination with an ultraviolet light source.

allowed to evaporate for 48 hours before planting 15 oat seeds in each pot. The oats were allowed to grow for 7 weeks. The number of surviving oat plants, the green weight, and the oven-dry weight of oats in each pot were then recorded.

RESULTS AND DISCUSSION

Both diuron and monuron showed photochemical changes when exposed to ultraviolet light (Figures 1 and 2). When not exposed to light, diuron gave a typical minimum in the percent transmittance curve at 249 mμ and monuron at 245 mμ. Diuron gave a maximum at 227 mμ, whereas monuron gave a maximum at about 218 mμ.

The changes in percent transmittance of light are best seen at 249 and 227 mμ for diuron and 245 and 220 mμ for monuron. Exposure of either chemical resulted in progressive changes in the percent transmittance of light in the ultraviolet region. The comparison of the exposures in the 245– to 250–mμ range probably gave the best indication, as the solvent interfered with transmittance of light at 215 mμ and below. Irradiation of either chemical tended to round out the curve of percent transmittance. The results indicate that diuron may undergo more rapid photochemical change than does monuron.

Samples of diuron and monuron were irradiated for 28 hours and then applied to soil in pots at rates equivalent to ½ and 2 lb/A. The effects of ultraviolet irradiation on the biological activity of diuron are shown in Table 1. Although the irradiated chemicals reduced the growth of oats 27 to 32 percent at ½ lb/A and 65 to 98.5 percent at 2 lb/A as compared with the control, they showed a 75–percent reduction in biological activity as compared with the non-irradiated chemicals. This is evident from the fact that 2 lb/A of irradiated chemical permitted as much growth of oats as that permitted by only ½ lb/A of non-irradiated chemical.

Table 1. Average oven-dry weight of oats per pot produced from soil samples treated with irradiated and non-irradiated herbicides.

Herbicide applied lb/A	Centigrams oats produced when herbicide used was:	
	Irradiated	Not irradiated
Monuron:		
½	93	3
2	2	0
Diuron:		
½	99	48
2	48	0
None: (control)	–	136

The photochemical changes in diuron and monuron and their reduced biological activity when exposed to ultraviolet light for a 28–hour period in this study suggest the possibility that similar photochemical changes may occur in natural sunlight when these herbicides lie on the soil surface for long periods after application

before being leached into the soil by rainfall or irrigation. This could be an important consideration in areas of limited rainfall and suggests need for additional studies in natural sunlight and absence of precipitation.

SUMMARY

Chemically pure samples of diuron and monuron were irradiated with an 85–watt mercury vapor ultraviolet lamp for 0, 2, 8, and 28 hours. Spectrophotometric determinations were made for each exposure with an automatic-recording DK–2 spectrophotometer. Samples of diuron and monuron were irradiated for 28 hours and then used to treat areas of soil on which oats were planted to determine any change in biological activity. The following can be concluded:

1. Diuron and monuron underwent a photochemical reaction when irradiated as measured by the percent transmittance of light in a spectrophotometer. There was progressive degradation with an increasing breakdown of chemical taking place with an increase in irradiation. The absorptions (negative transmittances) of monuron and diuron in the vicinity of 245 and 249 mμ, respectively, appear to be the spectral regions most affected by irradiation.
2. Diuron appeared to break down more rapidly than monuron.
3. Illumination of either chemical for a 28–hour period resulted in a 75–percent decrease in biological activity.

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Pre-emergence Weed Control in Soybeans with Mixtures of Two Herbicides[1]

J. R. Hay

Several herbicides have been tested for pre-emergence weed control in soybeans. PCP (sodium pentachlorophenate) has given good pre-emergence weed control in soybeans but relatively high rates of 15 to 20 lb/A were required (4, 8). Although CIPC (isopropyl *N*–(3–chlorophenyl)carbamate) and NPA (*N*–1–naphthylphthalmic acid) have given promising results in some tests they have not been uniformly good; CDAA, on the other hand, has consistently controlled annual grasses but not broadleaf weeds (6).

DNBP (dinitro ortho secondary butyl phenol) and CIPC have injured soybeans when applied at 8 lb/A (4). Pre-emergence applications of DNBP at rates safe to use on soybeans have given good control of most annual weeds except foxtails (*Setaria* spp.) and barnyardgrass (*Echinochloa crusgalli*). It was found that better control of grasses was obtained if the application of the DNBP was delayed until soybeans were in the "crook" stage (1, 3). Presumably, this was because the weeds were at a more susceptible stage of growth at this time. Injury to soybeans treated at the crook stage developed if the temperatures were over 80°F (3).

Staniforth and Weber (7, 9) found that under Iowa conditions average infestations of annual weeds caused reductions in soybean yields of 10 per cent. In another study they report that weed control by NPA, DNBP and CDAA was not superior to that obtained by judicious use of the rotary hoe and good cultivation practices (8). Similar conclusions were reached by Peters et al. (4). Lovely et al. (2) found that rotary hoeing must be done after weeds had germinated but before they had emerged. They also reported that 2 or 3 "timely" rotary hoeings reduced weed infestations by 70–80 per cent. Effectiveness was reduced by wet weather before or after the operations.

A pre-emergence treatment capable of giving full season weed control in soybeans would permit production of this crop on land now considered too weedy for soybeans. Need for rotary hoeing would be eliminated, timing of inter-row cultivation would be less critical and competition of weeds in the row would be eliminated. With a satisfactory pre-emergence herbicide, soybeans could be grown in solid stands.

Chemical weed control in a crop such as soybeans necessitates a high degree of selectivity because the aim is to destroy a large number of plant species without injury to the crop. With the exception of PCP at excessively high rates, none of the materials presently available has fulfilled this requirement. Since DNBP controls annual broadleaf weeds and CDAA controls annual grasses

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it was decided to test the effectiveness of mixtures of these materials. Preliminary tests in 1957 suggested that many species of annual weeds could be controlled by mixtures of these materials without injury to the soybeans. The results reported here are from experiments conducted in 1958 and 1959 to confirm the preliminary findings and to explore further the potentialities of the use of mixtures of herbicides.

MATERIALS AND METHODS

The experiments were conducted at Ottawa on soil ranging in texture from loam to sandy-clay loam. Mandarin soybeans in 1958 and Comet soybeans in 1959 were sown with a grain drill or by hand at a depth of 1.0 to 1.5 inches in rows 7, 21, or 36 inches apart. Plots were 18 feet long and not less than 8 feet wide. The experimental design was a randomized block with four replications.

Unless otherwise stated, the soybeans were sown in 1958 on May 21 or 22 and in 1959 between May 19 and 24. Average daily maximum air temperature for the period May 26 to June 8 (two-week period following herbicide applications) was 66.6°F in 1958 and 77.9°F in 1959. On only one day during this period, June 8, 1959, did the temperature go over 85°F, when the maximum air temperature was 91°F. During this two week period 0.97 inches of rain fell in 1958 and 0.44 inches in 1959.

CDAA, CIPC, DNBP, sodium salt of NPA, and a mixture of CDAA and DNBP were tested as residual pre-emergence herbicides. Band treatments were applied with a knapsack sprayer while overall treatments were made with a compressed-air sprayer mounted on sulky wheels and fitted with an 8 foot boom. All materials were applied in not less than 16 gallons of solution per acre. Applications were made 2 or 3 days prior to the emergence of the soybeans except in one test when applications were made at the time of planting.

Plots were trimmed to 14 feet at harvest time and the centre row or centre four rows of the plots seeded in 7-inch rows, were sampled. Fresh weights of the weeds in these same areas were also determined at harvest time. These weights were used as a measure of the weed control for the growing season. Weeds were cut at ground level and above-ground parts were weighed in the field immediately after sampling.

Similar experiments were conducted in 1958 and 1959 except once where the two tests were run in 1959. Analysis of variance was run on the data for each year. The mean squares for error were pooled and Duncan's Multiple Range Test (5) was applied.

The most common weeds in the test areas were lambsquarters (*Chenopodium album* L.), rough pigweed (*Amaranthus retroflexus* L.), ladysthumb (*Polygonum persicaria* L.), ragweed (*Ambrosia artemisiifolia* L.), wild buckwheat (*Polygonum convolvulus* L.), green foxtail (*Setaria viridis* (L.) Beauv.), barnyardgrass (*Echinochloa crusgalli* (L.) Beauv.), purslane (*Portulaca oleracea* L.) and field pennycress (*Thlaspi arvense* L.).

RESULTS AND DISCUSSION

Comparison of mixtures of CDAA and DNBP with other herbicides.

Tests were conducted in 1958 and 1959 to compare the effectiveness of NPA, CIPC, CDAA and DNBP used alone with that of a mixture of CDAA and DNBP. The soybeans were seeded in rows 7 inches apart; no cultivation was given. The results are recorded in Table 1. Weed control obtained with the mixture of CDAA and DNBP was significantly better than with any of the other herbicides tested. Soybean yields from plots treated with the mixture were significantly higher than from plots treated with any of the other materials at 4 lb/A, but not greater than from those treated at 8 lb/A. DNBP was not applied at 8 lb/A because this rate had injured the soybeans in earlier tests.

Table 1. Yield of soybeans and weight of weeds at harvest time following application of various herbicides 2–3 days prior to emergence of the soybeans. Means of two years' results.

Treatment	Rate lb/A	Yield of soybeans, bu/A	Treatment	Rate lb/A	Pounds of green weeds per acre
CDAA + DNBP	4 + 4	29.6 [a]	CDAA + DNBP	4 + 4	310
CIPC	8	27.1	CDAA	8	1630
CDAA	8	26.6	CIPC	8	2170
NPA	8	24.9	CDAA	4	2440
DNBP	4	22.4	CIPC	4	2780
CIPC	4	20.7	DNBP	4	2990
CDAA	4	20.6	NPA	4	3040
NPA	4	19.6	NPA	8	3320
Check	–	16.1	Check	–	6180

[a]Vertical lines indicate groups of means within which it was not possible to demonstrate significant differences by Duncan's Multiple Range Test.

A slight "crinkling" of the plumular leaves of soybean seedlings in plots treated with CDAA, either alone or with DNBP, was noted. Later leaves were normal and no permanent damage or effect on yield was noted.

Effect of different proportions of CDAA and DNBP.

Tests were carried out to determine the effectiveness of CDAA and DNBP when mixed in different proportions. Soybeans were sown in 21 inch rows and cultivated between the rows twice during the growing season. Weeds in a 6–8 inch band over the row were not disturbed. Table 2 shows that there were no significant differences in effectiveness among the various mixtures. All were judged to give satisfactory weed control. The data suggest, however, that 2 lb/A of either material was near the minimum level for good weed control.

The check plots contained pigweed, lambsquarters, wild buckwheat, green foxtail and barnyardgrass. Predominant weeds in the CDAA treated plots were pigweed, lambsquarters and wild buckwheat while those in the DNBP treated plots were almost exclusively barnyardgrass and green foxtail. Although a few plants of each species were found in the plots treated with the "mixtures" none was considered to be resistant to the treatment.

Table 2. Yield of soybeans and weight of weeds following application of CDAA and DNBP, alone and in mixtures when applied 2–3 days prior to emergence of soybeans. Means of two years' results.

Treatment	Rate lb/A	Yield of soybeans, bu/A	Treatment	Rate lb/A	Pounds of green weeds per acre
Check, weed free	–	28.3			
CDAA + DNBP	4 + 3	26.4	CDAA + DNBP	4 + 4	200
CDAA + DNBP	4 + 4	26.2	CDAA + DNBP	4 + 3	440
CDAA + DNBP	6 + 3	25.1	CDAA + DNBP	6 + 3	470
CDAA + DNBP	4 + 2	25.0	CDAA + DNBP	2 + 3	740
CDAA + DNBP	2 + 3	24.6	CDAA + DNBP	4 + 2	920
CDAA	6	22.1	CDAA	6	1480
DNBP	4	20.7	DNBP	4	1610
Check	–	16.1	Check	–	5050

Effect of time of application of a mixture of CDAA and DNBP.

In the tests discussed above the materials were applied two or three days before emergence of the soybeans. Trials were also conducted to study the effect of applying mixtures of CDAA and DNBP at the time that the crop was seeded. There are practical advantages with applications made at this time rather than just before emergence. Some operators would prefer to plant and spray in one operation to save time and to avoid the possibility of having to delay the herbicide application because of inclement weather. Furthermore, it is easier to centre spray bands over the rows if the nozzles are attached directly to the planter.

Two tests were conducted in 1959. The first was seeded on May 24 and the second on June 4. Plots were treated at the time of planting and just before emergence. Average daily maximum air temperature for the period May 24 to June 20 was 74.2°F. On only three days did the temperature go over 85°F: on June 8, 9 and 10 the maximum air temperatures were 91, 91 and 89°F respectively. From May 24 to June 20, 1.60 inches of rain fell.

The herbicides were applied in 12 inch bands over the rows and the weeds between the rows were controlled by cultivation. Mean yields for the two tests are recorded in Table 3. In these tests there were no differences between times of treatment. However, since volatile herbicides such as DNBP are lost from the soil surface, better results would be expected in hot weather (i.e. at temperatures over 90°F) if the applications were delayed until just before emergence of the beans.

Table 3. Yield of soybeans and weight of weeds at harvest time following application of CDAA and DNBP at planting time and at emergence. Means of two tests conducted in 1959.

Time of application	Rate, lb/A		Yield of soybeans, bu/A	Time of treatment	Rate, lb/A		Pounds of green weeds per acre
	CDAA	DNBP			CDAA	DNBP	
At emergence	3	+ 3	27.9	At emergence	4	+ 4	790
At emergence	4	+ 4	27.5	At planting	4	+ 4	1400
At planting	4	+ 4	26.1	At emergence	3	+ 3	1490
At planting	3	+ 3	24.7	At planting	3	+ 3	1720
Check	–		9.5	Check	–		8730

Weeds controlled by these treatments included green foxtail, barnyardgrass, lambsquarters, pigweed, ragweed, purslane, and field pennycress.

Effect of a mixture of CDAA and DNBP when applied to soybeans planted at different row widths.

Additional experiments were carried out to determine which row spacing would result in the best return for the amount of CDAA and DNBP used. Soybeans were planted by hand one inch apart in rows spaced at 36 inches, two inches apart in rows spaced at 24 inches, and three inches apart in rows spaced at seven inches. In each replication there was a sprayed plot and an unsprayed plot for each row width.

A mixture of CDAA and DNBP, each at 3 lb/A, was applied a few days prior to emergence of the soybeans. Entire plots were sprayed for the 7-inch spacings but only 12-inch bands over the 24- and 36-inch rows were treated. Thus, the actual amounts of each herbicide applied were 3, 2 and 1 lb/A for the three row spacings. The soybeans in the 7-inch rows were never cultivated, whereas those in the wider rows were cultivated twice during the growing season. Mean yields for the experiments conducted in 1958 and 1959 are given in Table 4.

Table 4. Yield of soybeans and weight of weeds at harvest time in soybeans planted at different row widths following application of CDAA and DNBP, each at 3 lb/A 2–3 days prior to emergence of the soybeans. Means of two years' results.

Row spacing	Treatment	Yield of soybeans, bu/A	Row spacing	Treatment	Pounds of green weeds per acre
24 inches	herbicides	27.6	36 inches	herbicides	300
7 inches	herbicides	26.3	24 inches	herbicides	600
36 inches	herbicides	26.2	7 inches	herbicides	1450
24 inches	none	15.4	36 inches	none	4180
7 inches	none	13.6	24 inches	none	6380
36 inches	none	12.5	7 inches	none	7190

Excellent weed control and marked yield increases were obtained in the treated plots. There were no differences in soybean yields at the three row spacings. On the other hand, a significantly lower fresh weight of weeds resulted at the 36 inch row width, presumably because a greater portion of the area was cultivated at this spacing. Thus, not only did the widest row width require less chemical but also it resulted in the best weed control. On the basis of these results there was no advantage to using 24 inch rows rather than 36 inch rows. The factors influencing the choice between the 7 and 36 inch rows would depend on the price of the herbicides and the cost of the two cultivations. If the additional seed and herbicides required for the solid stands cost more than the two cultivations, then the wide row spacing would be preferable. Also, if for some reason, the herbicides gave poor control it would always be possible to obtain a measure of weed control by inter-row cultiva-

tions. It is recognized that under other conditions there may be an optimum row width at which soybeans should be grown.

Effect of CDAA and DNBP on different varieties of soybeans.

In 1959 the soybeans in a six acre nursery at the Genetics and Plant Breeding Research Institute, Ottawa were sprayed with a mixture of CDAA and DNBP at 3 lb/A each. The lines were rated for their susceptibility to injury using an arbitrary scoring system (1 for no detectable injury to 10 for leaves killed). The results in Table 5 show that only moderate injury was noted although the lines varied somewhat in their response. Almost all of the injury was restricted to crinkling of the plumular leaves which, as was noted above, was caused by the CDAA. Trifoliate leaves of all lines were normal and no permanent injury was noted.

Table 5. Average rating for injury observed on plumular leaves of different varieties of soybeans treated with a mixture of CDAA and DNBP each at 3 lb/A. All varieties occurred in 1, 2 or 3 tests, each having four replications.

Variety	Number of tests	Average injury rating*
Chippewa	1	1.1
Mandarin	3	1.1
Grant	2	1.3
Hardome	2	1.5
Capital	2	1.5
Crest	2	1.5
Flambeau	3	1.6
Merit	1	2.2
Acme	2	2.4
Comet	2	2.5
Norchief	3	5.3

*1 = no effect; 10 = leaves killed.

CONCLUSION

In tests conducted over a period of three years a mixture of CDAA and DNBP, each at 3 to 4 lb/A, has consistently given better control of annual weeds in soybeans than either CIPC, NPA, CDAA or DNBP alone.

Green foxtail, barnyardgrass, lambsquarters, rough pigweed, purslane, ragweed, field pennycress and wild buckwheat were controlled by this mixture.

Although some varieties of soybeans were more susceptible than others to a distortion of the plumular leaves, which was caused by the CDAA, none has been permanently injured at the rates used.

The data indicated that between 2 and 3 lb/A was the lowest rate at which either should be used and that optimum results were obtained with between 3 and 4 lb/A of each material.

Under the conditions described, comparable results were obtained with applications made at planting time and just prior to the emergence of the soybeans.

Under conditions at Ottawa in 1958 and 1959 there were no differences in yields of soybeans planted in rows 7, 24 inches and

36 inches apart. From the standpoint of weed control obtained and amount of herbicide required, the best results were obtained by band applications over rows 36 inches apart.

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The Medusahead Problem in Idaho[1]

PAUL J. TORELL[2], LAMBERT C. ERICKSON[3], and ROBERT H. HAAS[4]

INTRODUCTION

MEDUSAHEAD, *Elymus caput-medusae* L., is currently the worst range weed in Idaho. It has gained this distinction because of its rapid migration, its vigorous competitive nature, and its extremely low forage value. In the absence of effective control measures, the medusahead problem is becoming more acute each year. The threat that the weed poses to Idaho's livestock industry is sufficient to merit grave concern.

According to Abrams (1) medusahead is native to Europe. The same author points out that medusahead was first described by Linnaeus, in 1753. Thus, while the species is one of the earliest to be recorded by botanical science, it is a relatively recent introduction to the United States. Furbush (2) provides the earliest reference to medusahead in the United States by his account of a collection of the species made near Roseburg, Oregon, in 1887. St. John (9) noted another early collection of medusahead by G. R. Vasey near Steptoe, Washington, in 1901. The earliest authenticated specimen of medusahead in the University of Idaho Herbarium was collected in Owyhee County in 1946, by Ray J. Davis. However, ranchers in southwestern Idaho maintain that the weed was noticed in Gem County during the 1930 decade.

Although the origin of medusahead in Idaho is obscure, the species has demonstrated that it is capable of rapid migration. In 1952, Sharp and Tisdale[5] referred to a weed survey that indicated there were at least 30,000 acres of medusahead in Idaho. In 1955, Hironaka et al. (3) estimated that Idaho's medusahead infestation amounted to 150,000 acres. In 1959, the Bureau of Land Management[6] reported 700,000 acres of the weed in southwestern Idaho.

Idaho's largest medusahead infestation occurs in the southwestern part of the state (Figure 1). The recent survey by the Bureau of Land Management shows that the major portion of the infested area is in Gem, Payette, and Washington Counties. Smaller but

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[2]Assistant Agronomist, Idaho Agricultural Experiment Station, Parma, Idaho.

[3]Associate Agronomist, Idaho Agricultural Experiment Station, Moscow, Idaho.

[4]Formerly Research Agronomist, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, Twin Falls, Idaho. Now Assistant Professor, Department of Range and Forestry, Texas A .and M. College, College Station, Texas.

[5]L. A. Sharp and E. W. Tisdale, Medusahead a problem on some Idaho ranges, Univ. of Idaho Forest, Wildlife and Range Exp't. Sta. Res. note No. 3, May, 1952.

[6]Correspondence, Bureau of Land Management, State Office, Boise, Idaho, May, 1959.

Figure 1. The medusahead infestation in Idaho as of May 1, 1959.

still dangerous stands exist in Ada, Adams, Elmore and Nez Perce Counties. Somewhat minor infestations are known in Boise, Canyon, Latah, and Owyhee Counties.

THE NATURE OF MEDUSAHEAD AS A WEED

Medusahead is typically a winter annual species. However, with proper vernalization it can also develop as a spring annual. Bovey[7] found that sprouting seeds exposed to night temperatures of 35°F. for a period af 7 days produced plants which fruited normally. These results are supported by Major (4) who reported evidence of the necessity of a cold treatment for normal development and seed production.

The extremely aggressive and competitive characteristics of this weed were aptly described by Peck (7) who stated:

[7]R. W. Bovey, unpublished master's thesis, Univ. of Idaho Library. June, 1959.

"In southern Oregon, in the high hills east of Ashland, thousands of acres are covered, almost to the submergence of other forms of herbaceous vegetation, with a continuous mantle of *Elymus caput-medusae*, the Medusa-head grass."

To a similar degree, many thousands of acres of the foot-hill ranges in southwestern Idaho are dominated by a medusahead stand so dense and vigorous that the other herbaceous vegetation has been almost submerged. Figures 2 and 3 illustrate a typical medusahead stand in this area. The weed has practically eliminated downy brome (cheatgrass), *Bromus tectorum* L., and it is providing intense competition to the few resident perennial grasses and forbs that remain.

Figure 2. A typical stand of medusahead in southwestern Idaho. Some 700,000 acres are infested with the weed in this area.

Several inquiries have been received from ranchers concerning possible means of removing medusahead from established stands of desert wheatgrass, *Agropyron desertorum* (Fisch) Schult., and intermediate wheatgrass, *Agropyron intermedium* (Host) Beauv. Such invasions indicate that the weed can invade and become a problem on infested ranges that have been reseeded with wheatgrasses.

Experimental reseedings and observations on larger reseeded private ranges have established that in some instances this does happen. The evident result of atempting to reseed medusahead-infested ranges without adequate prior control of the weed has been a rapid suppression of the wheatgrasses, which are notably slow in becoming well established. The consequent result is that in one place a six-year-old stand of desert wheatgrass is known to be held in a state of suppression by medusahead competition (Figure 4).

Figure 3. A close-up view of the stand shown in Figure 2. Note the extremely dense medusahead cover that practically excludes desirable forage species.

Although more investigations are needed to assess fully the reasons for the weed's extreme competitive ability, it seems proper to ascribe a considerable amount of it to these circumstances: the species is a prolific seed producer; its seeds are highly viable and germinate readily; its vigorous seedlings have a high survival rate; and its herbage is very unpalatable to livestock.

Major et al. (5) believe that medusahead stands can possibly produce up to 6,000 seeds per square foot. Sharp and Tisdale[5] noted medusahead stands contained up to 1,855 plants per square foot. Sharp et al. (8) report germination of 98 percent for medusahead seed. Since medusahead is unpalatable, the plants gain an additional advantage by virtue of being avoided while the associated palatable species are heavily grazed. Bovey[7], in attempting to utilize the plant, found that ensiling did not soften the herbage nor make it acceptable to livestock. The same investigator reported that medusahead herbage contains 11.32 percent silicon dioxide as compared to 4.45 percent in cheatgrass. This might account for its unpalatable qualities and also for its slow rate of decomposition in the field.

Another attribute that contributes to medusahead's potential as a range weed is the fact that the species is possessed of a broad ecologic amplitude. Throughout the extreme range of the known medusahead stands in Idaho, from Owyhee County to Nez Perce County (Figure 1), the weed occurs on soils that vary widely in profile development, depth, and subsoil characteristics. Laboratory studies by Erickson[8] show the species is adapted to soils varying widely in textural and chemical composition. McKell et al. (6)

[8]L. C. Erickson, unpublished data.

Figure 4. A six-year-old stand of desert wheatgrass held in a state of partial suppression by medusahead.

report that medusahead is the number one annual weed problem on a California range having an annual rainfall of 39.6 inches. In Idaho the weed is supplanting cheatgrass and competing with weakened resident perennial grasses on ranges whose annual precipitation varies from 10 to 20 inches. Parish[9] investigated the climatic characteristics of the medusahead-infested areas in the western states. He noted that seasonal periodicity of precipitation was of greater significance than total precipitation in the moisture requirement of the species. Generally, medusahead was found to be associated with regions of fall, winter, and spring precipitation followed by dry summers. This climate is essentially true of all of Idaho's some 6,000,000 acres of cheatgrass ranges. These considerations provide no evidence to presume that the weed is not adapted to all of the state's cheatgrass ranges.

[9]R. L. Parish, unpublished master's thesis, Univ. of Idaho Library, June, 1956.

Medusahead has an additional characteristic that adds to its problem as a weed. The dead herbage from each year's growth decomposes more slowly than is true of ordinary plant tissue, and a considerable amount of litter accumulates. A notable result of this litter is to suspend medusahead seed above the mineral soil where it survives at least one year following its maturation on the plants. This "old" seed is a significant factor in the perpetuation of the weed where control operations eliminate only a single year's medusahead growth. Also, the litter impedes tillage operations, and it adds to the total combustible material.

ECONOMIC LOSSES FROM MEDUSAHEAD

Forage losses constitute an important part of the medusahead problem. With reservation for the inaccuracies involved in ascribing a monetary value to range weed losses, Parish[9] suggested that a gross annual loss of five dollars per acre might be attributed to medusahead on the infested ranges in southwestern Idaho. If this figure is applied to the 700,000 acres of medusahead reported by the Bureau of Land Management[6], an annual gross loss of $3,500,000 might be charged to medusahead in this one area of Idaho.

The potential threat that medusahead poses to Idaho's ranges must also be considered. If the species were to occupy all of the state's some 6,000,000 acres of downy brome, the full impact would be reckoned in terms of the loss of spring and fall use that these ranges now furnish. The elimination of these seasons of range use would be catastrophic to range livestock operations as they are now practiced.

Finally, medusahead-infested ranges are an extreme fire hazard. The cost of suppressing medusahead fires has become a matter of great concern to the Bureau of Land Management. Personnel from this organization reported an expenditure in excess of $10,000 to control one 22,000-acre medusahead fire, in 1958.

PROSPECTS FOR MEDUSAHEAD CONTROL IN IDAHO

The immediate problem that prevails in southwestern Idaho indicates a pressing demand for reseeding studies. It is evident that some method which will ensure the successful establishment of forage grasses on these ranges offers the best promise of securing some control of the weed and of realizing a return greater than the negligible amount that is now being obtained.

On the basis of research already accomplished it is clear that the requirements for medusahead control are easier stated than achieved. Past research failures to obtain satisfactory stands of forage grasses on medusahead sites have shown that a single operation to control the weed prior to the seeding of the forage species is not adequate. Sufficient medusahead seeds have remained to provide a stand of the weed so dense that the forage seedlings cannot survive.

Recent investigations have combined burning, dalapon, discing,

and plowing in various combinations which have provided for the control of two successive medusahead seed crops prior to seeding the desired forage species. The results obtained to date have been encouraging: it appears that sufficient control has been achieved to permit desert wheatgrass seedlings to become established. However, it remains to be determined whether the control has really been sufficient to assure the survival of wheatgrass stands. Unless the resurgence of medusahead is delayed long enough to permit the development of a vigorous stand of desert wheatgrass, the weed can be expected to form a dense stand that will hold the wheatgrass in a state of perpetual suppression.

As a means of securing the necessary degree of medusahead control, burning deserves particular consideration. A single burn will not remove sufficient medusahead seed to permit the successful establishment of wheatgrasses. In this regard, Erickson[8] has found that the thermal death point of medusahead seed is relatively high as compared with that of other grass species. A temperature of 232°F. over a period of 7 minutes was necessary to devitalize the seed completely. However, burning will enhance the effectiveness of tillage and herbicidal treatments by removing the heavy layer of medusahead litter, by destroying some seed, and by placing the remaining seed in contact with the mineral soil where they can be germinated and subsequently destroyed. With the possibilities that controlled burning appears to offer, a considerable amount of experimentation is indicated. This should include date-of-burning studies by season as well as repeated burning by years. These treatments should be incorporated in combination with tillage and herbicides followed by reseeding with desirable forage species.

Although the control of established medusahead stands primarily depends on the development of methods by research, the importance of prevention deserves much more attention than it has received. It is a strange paradox that a weed which poses a serious threat to Idaho's livestock industry is recognized by few people beyond the infested areas. Consequently, the migration of medusahead into a new location often is not noticed until a sizable area that livestock will not graze develops. By this time it is not feasible to eradicate the weed, and it simply continues to spread.

Besides the need for the recognition of medusahead and a systematic attempt to locate new infestations by annual surveys, every possible means should be utilized to rehabilitate susceptible cheatgrass ranges. Ideally, those ranges should be reseeded to well-adapted perennial grasses. Even though a reasonably satisfactory method can probably be developed for reseeding medusahead ranges, it will in all probability be easier and more economical to reseed before a new range area is infested with the weed.

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Responses of Corn Hybrids to Yellow Foxtail Competition[1]

DAVID W. STANIFORTH[2]

INVESTIGATIONS of the competitive effects of *Setaria lutescens* (Weigel) F. T. Hubb. (yellow foxtail) on corn have dealt primarily with the factors of crop and weed populations, nitrogen fertilizer applications, duration of the period of competition and the amount and distribution of seasonal rainfall. Differences in the competitive efficiencies of various crops and weeds have been demonstrated under various production conditions, but relatively less is known regarding competitive efficiencies among varieties of given crop species. Working under the dryland conditions of Western Canada, Pavlychenko and Harrington (4) compared the competitive efficiencies of several small grains. They ranked barley as the most efficient competitor of weeds, followed by spring rye, wheat and oats in that order. The importance of fertilizer applications in increasing the competitive efficiency of crops has been investigated widely (1,2,5). Previous studies with corn (5) and soybeans (6,7) have demonstrated some aspects of the role of soil moisture in determining the nature and extent of weed competition in these crops.

In the present study, the competitive efficiencies of four corn hybrids were evaluated under conditions of heavy yellow foxtail infestations on soils of varying nitrogen fertility. The four hybrids ranged in maturity from early to late for the experimental area.

MATERIALS AND METHODS

Experiments were conducted at Kanawha, Iowa, on Webster silty clay loam soil, in 1958 and 1959. The experimental area was in continuous corn production for 7 years prior to 1958 and was heavily infested with yellow foxtail (*Setaria lutescens*). During the period 1954–1957 the area had received yearly an overall application of 300 lb/A of 0–20–20 fertilizer prior to corn planting and applications of ammonium nitrate (33.5–0–0) to specific experimental plots at rates of 0, 70 and 140 lb/A of nitrogen. The same fertilizer treatments were continued during these experiments.

Experimental design was a split-plot, randomized block with four replications. Levels of nitrogen application were main plots; corn hybrids and levels of foxtail infestations were the sub-plots. Individual plots were 4 rows by 14 hills, of which 2 rows by 10 hills were harvested. Extra border rows were included between main plots.

Four corn hybrids were planted in hills 20 inches apart, in rows 40 inches apart. Hybrids and their respective maturity designations

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[2]Professor, Department of Botany and Plant Pathology.

for the area, were AES 801 (late), Ia. 4376 (adapted-late), Ia. 4570 (adapted) and Ia. 4630 (early-adapted). After emergence the corn plants were thinned to a uniform stand of 16,000 plants per acre and yellow foxtail infestations were established at levels of none and heavy. Heavy foxtail infestations consisted of 50–75 plants per square foot, in a band 6–8 inches wide in the rows of corn hills. Tractor-mounted equipment, with inside shovels removed, was used to cultivate corn rows. Broadleaved weeds were removed by hand weeding throughout the season.

Yields of mature foxtail were obtained in early September in both years, and calculated on the basis of pounds of dry matter per acre. Corn plots were hand harvested at maturity and the yields calculated in bushels per acre of shelled corn with 15½ percent moisture.

Table 1. Yields from 4 corn hybrids at 3 rates of nitrogen fertilization; and dry matter yields of mature foxtail. Data for 1958 and 1959 combined.

Hybrid	Nitrogen applied lb/A	Yield of corn, bu/A		Difference due to foxtail, bu/A	Yield foxtail lb/A
		Weed-free	Weedy		
AES 801	0	63.3	22.4	40.9	950
Late	70	101.3	53.5	47.8	1650
	140	125.5	100.3	25.2	1600
Mean, N levels		96.7	58.7	38.0	1400
IA. 4376	0	42.4	18.0	24.4	990
Adapted-late	70	89.2	45.6	43.6	1650
	140	124.8	104.3	20.5	1800
Mean, N levels		85.4	52.8	32.6	1480
Ia. 4570	0	52.0	26.6	25.4	1150
Adapted	70	97.5	57.4	40.1	1350
	140	122.4	108.7	13.7	1880
Mean, N levels		90.6	64.2	26.4	1460
Ia. 4630	0	52.3	24.1	28.2	1080
Early-adapted	70	89.4	65.8	23.6	1760
	140	120.1	113.4	7.7*	1520
Mean, N levels		87.6	67.7	19.9	1450

*Not significant at P = .05.

RESULTS

Conditions were similar in both seasons, except for moderate variations in seasonal rainfall and initial soil moisture reserves in the spring. In 1958 soil moisture reserves were adequate at the time of planting; seasonal rainfall was low and was characterized by a dry period from mid-July until fall. Soil moisture reserves in the spring of 1959 were below normal, but seasonal rainfall was relatively high and was distributed uniformly over the growing season. Yields of both weed-free and weedy corn were slightly higher in 1958 with all hybrids except AES 801. With this hybrid, yields were moderately higher in 1959. Yields of mature foxtail were approximately the same in both years. Yield data for the two years were combined and are presented in Table 1.

Responses of hybrids to the effects of yellow foxtail competition varied with the three levels of nitrogen fertility maintained. With very low availability of soil nitrogen, AES 801 yielded about the

same as the other three hybrids when foxtail infestations were present, but under weed-free conditions it yielded appreciably more. Thus the yield reduction due to foxtail competition was markedly greatest with AES 801 at the lowest nitrogen fertility level. With fertilizer application of 70 pounds of nitrogen and with no weed competition, the late maturing AES 801 yielded significantly more than the early maturing hybrid Ia. 4630. With foxtail competition however, the yield of Ia. 4630 was significantly higher than either of the late maturing hybrids. Hence, with Ia. 4630, the yield reduction due to foxtail competition was markedly less than with the other three hybrids.

At the highest level of nitrogen fertilization, yields of all four hybrids were about the same under weed-free conditions. With foxtail competition yields of Ia. 4630 were much greater than those of either AES 801 or Ia. 4376.

Most of the observed yield differences from year to year occurred under weed-free conditions. A better estimate of the responses of hybrids to yellow foxtail competition was obtained from the values for bushels of corn yield reduction per hundredweight of foxtail. These data were calculated and analyzed by the variance method, and are presented in Table 2.

Table 2. Bushels of corn yield reduction per hundredweight of mature foxtail for 4 hybrids, with 3 levels of nitrogen fertilization. Data for 1958 and 1959 combined.

Nitrogen applied lb/A	Hybrids				
	AES 801	Ia. 4376	Ia. 4570	Ia. 4630	Mean
0	4.60	2.36	2.26	2.74	2.98
70	3.00	2.68	1.99	1.58	2.56
140	1.52	1.34	.77	.61	1.06
Mean	3.04	2.13	1.99	1.64	

L.S.D. values at P = .05.		
	Between means of hybrids	.49
	Between means of nitrogen levels	.61
	Between hybrids within nitrogen level	.86
	Between nitrogen levels within a hybrid	.96

Values for corn reduction per hundredweight of foxtail were lowest for all hybrids with the high level of nitrogen fertilizer. Values for AES 801 were consistently highest, and those for Ia. 4630 were generally lowest. Values for hybrids Ia. 4376 and Ia. 4570 were intermediate. These patterns were most clearly expressed with 70 and 140 pounds nitrogen fertilizer treatments. With no nitrogen fertilizer, AES 801 was clearly the poorest competitor with weeds; the other hybrids were equal.

In the 2-year combined analysis of variance for corn yield, mean squares among nitrogen fertilizer treatments, years, foxtail levels and varieties exceeded the 1% level of probability. Of the primary interactions, varieties × foxtail levels, nitrogen levels × foxtail levels, and varieties × years exceeded the 1% level of probability.

In the analysis of variance of corn yield reduction per hundredweight of foxtail mean squares among nitrogen levels, varieties

and the interaction nitrogen levels × varieties exceeded the 1% level of probability. Mean squares for years and for all other interactions were low.

DISCUSSION

The foregoing results illustrate some of the hazards which may attend attempts to assess the competitive effects of weeds on corn, and emphasize the importance of hybrid adaptation in such studies. The consistent and significant difference in tolerance of foxtail competition between late maturing AES 801 and early maturing Ia. 4630 was pronounced at all levels of nitrogen fertility and in both seasons. With hybrids of intermediate adaptation and maturity range, Ia. 4570 and Ia. 4376, the pattern was similar though less extreme. At low nitrogen levels particularly, these two intermediate hybrids were almost identical with Ia. 4630 in response to foxtail competition. These observed response patterns suggest that under production conditions where weed competition is severe, the choice of hybrid might be of lesser importance than under conditions where the competitive effects of foxtail are less severe, as with high nitrogen fertilizer applications. Thus at higher levels of corn production, the responses of late maturing hybrids might exaggerate the potential losses expected from weed competition, while the results obtained with an extremely early hybrid might tend to minimize the effects of weed competition on corn yields.

The data obtained in this study do not explain fully the differential responses of hybrids to foxtail competition. Previous studies (3,5) have shown that little or no corn yield reduction resulted when foxtail was allowed to grow with corn until mid-July, particularly with high nitrogen fertility or with light weed infestations. In the present experiments, foxtail matured in mid-August. Thus during the period from late July through August, competition between foxtail and corn, probably was most severe. This suggests that the early maturing hybrid was past a critical period in its growth before the onset of severe foxtail competition. Conversely, the late maturing hybrid may have been subjected to severe foxtail competition at a critical or vulnerable period in its growth pattern.

The effects of high nitrogen fertilizer applications in minimizing the competitive effects of foxtail were consistent with previous experience. The results obtained herein are in close agreement with the estimates of corn yield losses due to foxtail competition, obtained in previous studies (3,5) with hybrids adapted in maturity to the experimental sites. It is recognized that different estimates of corn yield reductions might be obtained with other hybrids, in other seasons, at other locations and with variations in rainfall, soil fertility, corn plant populations and weed species.

SUMMARY AND CONCLUSIONS

The responses of four corn hybrids to the competitive effects of heavy infestations of yellow foxtail were investigated over a two

year period. The hybrids ranged in maturity from early-adapted, through adapted, to late. Additional variables included three levels of soil fertility, obtained with differential nitrogen fertilizer applications. Dry matter yield of above ground plant parts of foxtail, and yields of mature corn were obtained. The values for bushels of corn yield reduction per hundredweight of foxtail were calculated and used as the basis for comparisons of hybrid responses to foxtail competition.

In both years, bushels reduction per hundredweight foxtail for the late maturing hybrid AES 801 were approximately double those of the early adapted hybrid, Ia. 4630. The difference was greatest under conditions of high nitrogen fertilization. The responses of intermediate maturity range hybrids, Ia. 4570 and Ia. 4376, were intermediate between the late and early hybrids.

The importance of hybrid maturity range and adaptation to experimental locations in corn-weed ecological studies is emphasized. The possible effects of uncontrolled environmental and biological factors on the results is recognized.

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Pre-emergence Herbicides for Crabgrass Control and Their Effects on Germination of Turfgrass Species[1]

FELIX V. JUSKA[2]

DURING the past several years, pre-emergence herbicides for crabgrass control in turf have come into prominence. Some herbicides are relatively new; others, such as lead arsenate, calcium arsenate, and chlordane, have been used as herbicides for a number of years. Research workers have included the old as well as the newer herbicides in experiments under controlled conditions to determine their effectiveness as pre-emergence herbicides. However, information on the effect of these herbicides on the germination and growth of turfgrass species is limited. Application of lead arsenate as orchard sprays over the years had a toxic effect on the soil after the orchards had been removed and the areas planted to other crops due to arsenic accumulation. The poor condition of young alfalfa and barley in the affected fields was roughly proportional to the concentration of readily soluble arsenic in the surface soil (3).

Arsenic uptake by some grass plants may be injurious according to Daniel (1). In his studies, injury to *Poa annua* L. (annual bluegrass) was still evident 3 years after an application of 30 pounds of lead arsenate per 1,000 square feet when the phosphorus supply of the soil was low. Soils high in phosphorus required a higher arsenic accumulation before growth of annual bluegrass was inhibited. Fuchigami and Youngner (2) found that products containing approximately 5 percent water soluble arsenic were highly toxic to clover and discolored turfgrasses.

There are many variables which influence the toxic effect of pre-emergence herbicides, among which may be listed pH, organic matter, phosphorus and potassium levels, thatch, and soil type.

The study reported herein was designed to provide information on the following questions: 1. How long before crabgrass germinates can pre-emergence herbicides be applied and give effective control? 2. How soon can turfgrass species safely be seeded after applications of pre-emergence herbicides? 3. What is the relative susceptibility of turfgrass species to injury by pre-emergence herbicides?

MATERIALS AND METHODS

In the greenhouse, 34 flats, 2 feet square in area, were filled with greenhouse potting soil testing very high in P_2O_5 and high in K_2O, with a pH of 6.1. Seven herbicides, chlordane (50% wettable powder); calcium arsenate (tricalcium arsenate 85%, water soluble arsenic 4%); lead arsenate (98% arsenate of lead); fenac (2,3,6–

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[2]Research Agronomist, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, Beltsville, Maryland.

trichlorophenylacetic acid, amide and sodium salt formulations); chlordane + lead arsenate; arsenic complex + 7% nitrogen (water soluble metallic arsenic 19.02%); DMA (disodium monomethyl arsonate, a postemergence herbicide); and chlordane on vermiculite, were applied to the soil surface at several different rates (Table 1). Herbicides without a carrier were applied as a spray or mixed with sand. Kentucky bluegrass, *Poa pratensis* L., var. Merion, and annual bluegrass were seeded immediately after the application of herbicides and at monthly intervals thereafter for 4 months. Colonial bentgrass (*Agrostis tenuis* Sibth.) was included at the third and fourth seeding dates. Stand counts were made at monthly intervals after planting. However, since some of the seedlings died after emergence, Table 1 is based on a final count obtained by removing each plant at the termination of the experiment.

A similar study was established in the field on a silty loam, high in phosphorus and potassium and with a pH of 5.5. The area had been fumigated with methyl bromide 2 weeks before the establishment of the experiment. In addition to the herbicides mentioned previously, dimethyl 2,3,5,6–tetrachloroterephthalate (DAC–893); 0–2,4–dichlorophenyl 0–methyl isopropylphosphoramidothioate (M–1329); and diphenylacetonitrile (L–13489) were included. The ten herbicides were applied (one application of each) on the surface of the soil in plots 2 feet wide, replicated twice, and of sufficient length to accommodate 5 monthly plantings of several turfgrass species. The turfgrasses included Merion Kentucky bluegrass, annual bluegrass, red fescue (*Festuca rubra* L.), Colonial bentgrass, tall fescue, (*Festuca arundinacea* Schreb.), and vegetative plantings of *Zoysia japonica* Steud., var. Meyer, creeping bentgrass *Agrostis palustris* Huds. var. Arlington, and bermudagrass *Cynodon dactylon* (L.) Pers., var. U–3. Seed of turfgrass species was planted in June, the day after the herbicides were applied, and at monthly intervals for 5 months thereafter. Vegetative grasses were planted during a 3-month period beginning in June. Response of the turfgrasses to herbicide treatments was obtained visually and recorded in percent.

A third test was established to determine the length of time that several pre-emergence crabgrass herbicides would remain toxic to germinating crabgrass (*Digitaria spp.*) seed. This study was conducted in the fall of 1958 and spring of 1959 on turf that was largely common Kentucky bluegrass; however, in the fall of 1958, 90 to 95 percent of the area was infested with crabgrass. The test area was mowed at a height of 2 inches throughout the growing season. The soil, a sandy loam, pH 5.2, tested high in P_2O_5 and very high in K_2O. Herbicide treatments included fenac, calcium arsenate, lead arsenate, arsenic complex + 7% nitrogen, chlordane, chlordane or vermiculite, chlordane + lead arsenate, emulsifiable chlordane (72% chlordane), and no treatment. The herbicides were applied at 3 different times of the year, each block on a different date—November 15, 1958, February 15, 1959, and April 1, 1959. Applications were made with a knapsack sprayer at pressures of 35 to 40 pounds psi for wettable and soluble materials and with

sand as a carrier for the other herbicides. The plots were 5 feet by 5 feet, and the treatments were replicated 3 times in a randomized-block design.

The percentage of crabgrass as ground cover present in each plot is reported as the average of 2 independent visual estimates made in October 1959, after a killing frost had turned the crabgrass brown.

RESULTS AND DISCUSSION

A comparison of the effect of pre-emergence crabgrass herbicides on the germination of Merion Kentucky and annual bluegrasses in the greenhouse is found in Table 1. Fenac formulations, arsenic

Table 1. Effect of one application (November 19, 1958) of pre-emergence herbicides on the germination and growth of Merion Kentucky and annual bluegrasses seeded on four different dates, greenhouse 1958–1959. Data recorded as number of plants remaining in the plots at the termination of the trial.

Herbicide	Rate lb/A	Merion Kentucky bluegrass plants for indicated planting dates					Annual bluegrass plants for indicated planting dates				
		Nov. 19 1958	Dec. 3 1958	Jan. 5 1959	Feb. 19 1959	Average	Nov. 19 1958	Dec. 3 1958	Jan. 5 1959	Feb. 19 1959	Average
None		80	69	75	77	75	86	72	82	91	83
Fenac[a] (sodium salt)	4	0	0	1	1	1	0	1	0	8	2
Fenac (sodium salt)	6	0	0	0	3	1	0	2	4	3	2
Fenac (amide)	4	0	0	0	0	0	0	0	0	3	1
Fenac (amide)	6	0	0	0	0	0	0	0	0	3	1
Calcium arsenate	350	68	55	61	69	63	77	60	51	84	68
Calcium arsenate	520	49	55	60	61	56	38	34	33	71	44
Lead arsenate	440	80	76	57	64	69	90	88	80	88	87
Lead arsenate	870	69	67	48	62	62	89	89	85	87	88
Lead arsenate	1740	64	68	35	67	59	85	86	79	85	84
Arsenic complex + 7% nitrogen[b]	1090	23	4	7	18	13	11	0	1	1	3
DMA	15	70	68	64	69	68	84	79	93	84	85
Chlordane	65	12	2	1	1	4	90	45	45	52	58
Chlordane	130	1	0	0	0	0	35	46	45	63	47
Chlordane	260	1	1	2	0	1	51	44	46	23	41
Chlordane on vermiculite (commercial)	52	12	5	10	2	7	93	83	58	71	76
Chlordane + lead arsenate	65 + 440	1	0	1	4	2	55	60	36	38	47
Average for dates:		31	28	25	29		52	46	43	50	

L.S.D. .05 between dates = 4
L.S.D. .05 between chemical averages = 11
[a]Very toxic to seedlings.
[b]Severe injury to seedlings.

complex + 7% nitrogen, and chlordane severely reduced the germination of Merion bluegrass. Similar results were obtained for annual bluegrass except that the toxic effect of chlordane was much less severe. Fenac and arsenic complex + 7% nitrogen did not greatly inhibit germination of Merion and annual bluegrasses; however, the grass plants soon became chlorotic and died. A few plants of Merion bluegrass survived in the chlordane-treated soil. Lead

arsenate at 1740 pounds per acre did not appear to injure germinating bluegrass appreciably. Germination of annual bluegrass was not reduced materially in the greenhouse by lead arsenate treatment; however, this herbicide is frequently used over a period of time by golf course superintendents to reduce annual bluegrass populations in golf course greens. DMA, a postemergence herbicide frequently applied to control mature crabgrass before lawns are seeded in the fall, did not reduce the germination of Merion or annual bluegrasses. Calcium arsenate, under greenhouse conditions, reduced the stand of Merion and annual bluegrasses but not seriously.

Of the 4 monthly seedings of bluegrasses, only the January planting was significantly different from the first planting made in November. Herbicides which decreased the germination or retarded the growth of the seedlings remained toxic through the greenhouse experiment.

Bentgrass included in the last 2 plantings (January and February) was similar to Merion bluegrass in its reaction to the herbicides.

In the field, the turfgrasses were seeded at monthly intervals for 5 months. Regardless of treatment, crabgrass seed failed to germinate because of lack of preconditioning. Germination of 1 percent was obtained in chlordane-treated plots for Merion bluegrass and bentgrass planted immediately after treatment (Table 2). When

Table 2. Effect of several pre-emergence herbicides (applied June 4, 1959) on the germination and growth of various turfgrass species in the field, 1959. Data obtained one month after planting.

Herbicide and rate	Planting date 1959	Percent germination of				
		Merion Ky. bluegrass	*Poa annua*	Red fescue	Bentgrass	Tall fescue
None	June 5	95	100	100	100	100
	July 7	75	100	98	78	100
M-1329	June 5	0	0	0	0	0
20 lb/A	July 7	8	50	75	30	45
DAC-893	June 5	4	5	1	0	30
4 lb/A	July 7	0	28	73	40	98
DMA	June 5	98	98	100	100	100
15 lb/A	July 7	100	100	100	100	100
L-13489	June 5	75	100	100	52	100
12 lb/A	July 7	100	100	100	100	100
Calcium arsenate	June 5	13	0	55	9	22
520 lb/A	July 7	60	0	67	10	2
Lead arsenate	June 5	85	55	100	55	100
1090 lb/A	July 7	80	5	95	98	63
Arsenic complex + 7% nitrogen	June 5	2	0	0	0	0
1090 lb/A	July 7	28	0	2	0	0
Chlordane	June 5	1	38	75	1	90
87 lb/A	July 7	23	93	83	43	98
Chlordane on vermiculite	June 5	7	65	80	3	95
52 lb/A	July 7	49	83	90	50	100

planted 1 month later the germination of these grasses increased to 23 and 43 percent respectively. Red and tall fescue species apparently are highly resistant to toxicity of chlordane applied at the rate of 87 pounds per acre. Stands of these species were not reduced.

Planted immediately after treatment, the germination of annual bluegrass was reduced to 37 percent in chlordane-treated plots; however, the planting made 1 month later germinated almost as well as in the check. Arsenic complex + 7% nitrogen was toxic to all species and seedlings became chlorotic and in this trial died after emergence. One hundred percent control of annual bluegrass was obtained with 520 pounds per acre of calcium arsenate. Red fescue was most resistant to calcium arsenate injury followed by Merion bluegrass and tall fescue. Lead arsenate was more toxic to annual bluegrass in the field than in the greenhouse. Merion bluegrass and red and tall fescue seedlings appear to be highly resistant to lead arsenate toxicity. M–1329 and DAC–893 were toxic to germinating turfgrass species immediately after applications were made.

DMA was applied as a pre-emergence herbicide. The advisability of reseeding immediately after DMA applications prompted the inclusion of DMA in the study. DMA and L–13489 did not interfere with seedling emergence to any appreciable degree.

In August and September poor emergence of seedlings occurred in all treatments because of adverse weather conditions. The last seeding (October) was partially successful and the residual effects of 4 herbicides on several turfgrass species are shown in Table 3.

Table 3. Residual effects of four pre-emergence herbicides on several turfgrass species, five months after treatment.

Herbicide	Percent germination of				
	Merion Ky. bluegrass	*Poa annua*	Red fescue	Bentgrass	Tall fescue
None	88	83	95	80	88
Calcium arsenate 520 lb/A	50	35	75	40	43
Chlordane 87 lb/A	58	80	90	73	45
M-1329 20 lb/A	50	60	38	53	48
Arsenic complex + 7% nitrogen[a] 1090 lb/A	58[a]	75[a]	78[a]	53[a]	68[a]

[a]Seedlings died after emergence.

These data, obtained in November, indicated that the residual effects of calcium arsenate, chlordane, M–1329, and arsenic complex + 7% nitrogen was still evident. The deleterious effects of pre-emergence herbicides on seedling emergence may be considerably less in turf than in bare soil.

Germination of all turf species at later planting dates increased in the arsenic complex + 7% nitrogen-treated plots; however, a month after the October seeding most seedlings were dead.

The vegetatively planted species, zoysiagrass, bermudagrass, and bentgrass, in general, were less affected by the herbicides than when they were seeded, possibly because the roots were planted below the zone of toxicity. The arsenic complex + 7% nitrogen severely injured all 3 grass species for 3 months or more. Of the 3 vegetatively planted grasses, bermudagrass was most resistant to arsenic injury.

Calcium arsenate, M–1329, and DAC–893 also affected the vigor and growth of vegetatively planted turfgrass species but not for as long a period as the arsenic complex + 7% nitrogen. All herbicides except DMA and L–13489 decreased the vigor of vegetatively planted species to some degree.

To determine how long pre-emergence crabgrass herbicides will remain toxic to germinating crabgrass seed, applications of several herbicides were made on separate blocks of a thin turf of Kentucky bluegrass. Data are recorded in percent crabgrass as ground cover and average percent control for the 3 different dates of application (Table 4). Fenac was ineffective as a pre-emergence herbicide to

Table 4. Pre-emergence crabgrass control on bluegrass-red fescue turf, October 1959.

Herbicide	Rate lb/A	Time of application			Percent control
		Nov. 15 1958	Feb. 10 1959	March 31 1959	
		% crabgrass as ground cover			
None		91	84	89	0
Fenac (sodium salt)	4	99	88	65	4
Fenac (sodium salt)	6	99	88	78	−1
Fenac (amide)	4	98	92	53	8
Fenac (amide)	6	97	92	53	8
Calcium arsenate	350	23	37	13	72*
Calcium arsenate	520	3	12	3	93*
Lead arsenate	870	77	52	68	26*
Lead arsenate	1300	35	32	28	64*
Arsenic complex + 7% nitrogen	1090	0	3	5	97*c
Chlordane	65	83	77	38	25*
Chlordane	130	67	43	14	53*
Chlordane on vermiculite (commercial)	52	88	75	18	31*
Chlordane + lead arsenate	65 + 440	32	37	4	72*
Chlordane (emulsifiable)	65	—a	47	32	55*
Average:		64	57	37	

L.S.D. .05 time of application = 16
L.S.D. .05 herbicide within time of application = 29
*Difference from the check exceeds the .05 level of significance.

[a]Not applied in the fall.
[b]Temporary stunting and thinning of turf.
[c]Moderate to severe turf injury.

control crabgrass and severely injured existing turf. Spring applications of fenac gave slight control of crabgrass. Calcium arsenate at the rate of 520 pounds per acre was as effective when applied in the fall as when applied in the spring. Winter applications of calcium arsenate were somewhat less effective, perhaps, because the soil was frozen. The plots which received the lower rate of

calcium arsenate (350 pounds per acre) gave better control when applied in the spring. Temporary stunting and thinning of the turf were observed in the calcium arsenate-treated plots; however, these effects had largely disappeared by late fall. Lead arsenate was somewhat less effective as a pre-emergence herbicide than calcium arsenate.

No significant difference with respect to time of application and crabgrass control was obtained when lead arsenate was applied at the rate of 1300 pounds per acre. Arsenic complex + 7% nitrogen at 1090 pounds per acre effectively controlled crabgrass regardless of the time of application. Moderate to severe injury of turf was observed after each application of the herbicide. The stand of turfgrass began to thin out after treatment with the arsenic complex + 7% nitrogen and bare areas appeared in the turf 2 to 3 months later.

Fourteen percent crabgrass as ground cover was present in plots treated with chlordane (130 pounds per acre) in March; whereas, the plots receiving the treatment in the fall contained 83 percent crabgrass. The length of time that chlordane was toxic to crabgrass was less than that of the other herbicides used.

SUMMARY

1. Three experiments were carried out to study the effect of various pre-emergence crabgrass herbicides on the germination of several turfgrasses and to determine the length of time herbicides remain toxic to germinating crabgrass in turf.
2. In the greenhouse, fenac, arsenic complex + 7% nitrogen, and chlordane remained toxic to Colonial bentgrass and Merion Kentucky bluegrass throughout the experiment. Chlordane inhibited germination of Merion bluegrass more than that of annual bluegrass. Calcium arsenate gave better control of annual bluegrass in the field than in the greenhouse.
3. In the field, seedling emergence studies showed that all herbicides except DMA and L–13489 affected the germination of turfgrass species, with injury to turf ranging from little to severe. Arsenic complex + 7% nitrogen was more toxic than either calcium arsenate or lead arsenate. Chlordane affected the germination of Merion Kentucky bluegrass and bentgrass 3 to 4 months after application but had little effect on the other turfgrass species used. M–1329 and DAC–893 remained toxic to germinating seedlings 3 to 4 months. Vegetatively planted grasses withstood the toxic effect of the herbicides better than seedlings of the seeded species. Bermudagrass was more resistant to herbicide injury than zoysiagrass and bentgrass.
4. In the pre-emergence crabgrass control study in turf, no significant differences were found between calcium arsenate and arsenic complex + 7% nitrogen with respect to time of application. These herbicides effectively controlled crabgrass; how-

ever, arsenic complex + 7% nitrogen injured the turf. The fenac formulations did not satisfactorily control crabgrass and severely injured the turf. Chlordane was most effective when applied in the spring but did not satisfactorily control crabgrass.

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Phytotoxicity of Simazine[1]

O. C. Burnside[2] and R. Behrens[3]

Selective herbicides that will control certain broadleaved but not grassy species or vice versa have been in use for a number of years, but recently selective herbicides have been developed that are toxic to a greater number of weed species. Such an herbicide is 2–chloro–4,6–bis(ethylamino)–*s*–triazine (simazine) which selectively controls virtually all grassy and broadleaved annual weeds in corn and in some horticultural and woody species. This approaches the ultimate in selective weed control since a farmer usually wants to grow one plant species and eliminate all others.

Simazine was synthesized by Gysin and Knüsli in the laboratories of the Geigy Chemical Corporation, Basle, Switzerland (9). It was introduced in the United States in 1956 and since that time there have been numerous reports regarding its excellent herbicidal properties. Simazine is generally used as a pre-emergence herbicide because it enters the plant through the roots and is effective on young plants. Davis et al. (2) demonstrated root absorption of radioactive simazine, and showed that little simazine was absorbed by leaves unless the cuticle was broken. Present data indicate that corn is tolerant of simazine because it contains an enzyme system that deactivates this herbicide (8). Simazine is deactivated in susceptible plants also (2,8), but since its uptake by the susceptible species studied is more rapid, phytotoxic concentrations may accumulate in these species (2).

This study is concerned with crop response to simazine and the climatic and edaphic factors influencing simazine phytotoxicity.

Methods and Materials

General.

Technical simazine and Simazine 50W[4] were used in these experiments. Small aliquots of simazine were obtained by pipetting from dilute suspensions in water which were being stirred slowly with a "Magnestir". The plants used were corn, *Zea mays* L. (a single cross of A502 × A556); Kindred barley, *Hordeum vulgare*, L.; Marine flax, *Linum usitatissimum* L.; Clintland oats, *Avena sativa* L.; Caribou rye, *Secale cereale* L.; Flambeau soybeans, *Glycine max*

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[2]Formerly Research Assistant, Department of Agronomy and Plant Genetics, University of Minnesota. Now Assistant Professor, Department of Agronomy, University of Nebraska, Lincoln, Nebraska.

[3]Associate Professor, Department of Agronomy and Plant Genetics, University of Minnesota.

[4]Supplied through the courtesy of the Geigy Chemical Corporation, Yonkers, New York.

(L.) Merr.; and Selkirk wheat, *Triticum aestivum* L. Unless otherwise indicated, the thermostatic temperature control in the greenhouse was set at 75°F. during the experiments. The above-ground parts of the plants were harvested and dried at 212°F. for three days before weighing. All of the soils used were screened, thoroughly mixed, and stored in bins. Soil weights were calculated on an oven-dry basis. The soils were analyzed for a number of properties (Table 1). Soil pH measurements were made with a glass electrode

Table 1. Analyses of the soils used in this study.

Soil type	pH	Org. mat. %	Cation exch. cap.[a]	Sand % 2–0.05 mm	Silt % 0.05–0.002 mm	Clay % below 0.002 mm	Avail. P lb/A	Exch. K lb/A	Moist. % at 1/3 atm.	Moist. % at 15 atm.
Waukegan silt loam	5.4	4.0	16.8	19.4	52.0	28.6	180	480	25.2	9.6
Muck	6.9	40.7	65.5	42.6	31.3	26.1	22	180	89.0	62.3
Fargo clay	7.9	10.9	30.1	31.6	34.3	34.1	200+	600+	40.4	22.2
Sand	8.3	0.1	1.2	90.4	2.0	7.6	12	50	1.7[b]	0.7

[a]Cation exchange capacity is expressed in milliequivalents per 100 grams of oven-dry soil.
[b]This analysis made at 1/10 atmosphere pressure.

pH meter with the soils at their water saturation percentage (4). Organic matter was determined gravimetrically by oxidation with hydrogen peroxide according to the method described by Jackson (4). The hydrometer method for determining soil texture as developed by Bouyoucos (1) was followed. The neutral ammonium acetate method for determining cation exchange capacity (5) was utilized. The method described by Richards (6) was employed to determine ⅓ atmosphere and 15 atmospheres moisture tension measurements which are used to estimate field capacity and wilting coefficient, respectively, of a soil. Available phosphorus and exchangeable potassium were determined by the procedure described by Grava.[5] Experimental results were subjected to an analysis of variance, and significant differences among treatments were tested with Student-Newman-Keuls (SNK) mutiple range tests at the 5 per cent level of significance (12).

Quantitative determination of simazine in soil.

Oats, soybeans, and corn were used in bioassays to determine different concentrations of simazine in the soil. An oat bioassay was adapted from a procedure described in a personal communication.[6] In this method, 500 grams of Waukegan silt loam were mixed with the desired quantity of simazine and placed in a 16-ounce waxed paper cup. Thorough incorporation of simazine in the soil was accomplished by vigorous shaking and numerous rotations in a plastic bag. Ten oat plants were grown in each cup. The soil was watered from above

[5]Grava, J. Soil analysis methods as used in the University of Minnesota soil testing laboratory. University of Minnesota mimeograph. 1957.
[6]F. W. Slife, Associate Professor of Agronomy, University of Illinois, Urbana, Illinois.

whenever the surface was dry, usually once a day. Thirty days after planting, the above-ground parts of the plants were harvested, oven-dried, and weighed. A randomized block experiment was conducted where oats was grown in soil containing 0, 0.03, 0.06, 0.12, 0.25, 0.50, 1.00, 2.00, and 4.00 ppmw of simazine.

In soybean bioassays, 500 grams of Waukegan silt loam were mixed with the desired quantity of simazine and placed in a four-inch clay pot that had a small piece of paper towel over the hole in the bottom to prevent soil loss. Six soybean plants were grown in each pot. The plants were watered by subirrigation every other day during the beginning of the growth period and every day during the latter part of the growth period. Thirty days after planting the above-ground parts of the plants were harvested, dried, and weighed.

A randomized block experiment with five replications was conducted to determine if simazine was lost by subirrigation. Half of the pots in the experiment were handled according to the soybean bioassay technique while the drain holes of the other half of the pots were sealed with corks. The sealed pots were watered from the top with the same amount of water as was taken up by the soil in the subirrigated pots. The average yield of soybeans grown in 4 ppmw of simazine was 0.51 grams of dry material per pot when subirrigated and 0.50 grams per pot when sealed pots were watered from the surface. These results showed that no detectable amount of simazine was lost due to subirrigation. Subirrigation was used in subsequent experiments because it was a very uniform method of watering.

Three randomized block experiments with five replications were conducted to determine the influence of different growing conditions on the yields of soybean bioassays used to detect known quantities of simazine. The first test was conducted in a controlled temperature growth chamber which was maintained at about 73°F. during 18 hours of exposure to an 800 footcandle light intensity and about 68°F. during six dark hours of the 24-hour cycle. The second test was conducted in a greenhouse with the thermostatic temperature control set at 75°F. and at no time during this period did the outside temperature go higher than 73°F. The third experiment was conducted in a greenhouse with the thermostatic control set at 75°F. However, during this test the outside temperature went above 75°F. on eight days. Therefore, eight days during the growing period of this test the temperature exceeded 75°F. since there was no means of cooling the greenhouse, except by allowing outside air to enter through thermostatically controlled vents.

A corn bioassay was used because this plant responds to extremely high concentrations of simazine. In this bioassay, 3,500 grams of Waukegan silt loam were mixed with the desired quantity of simazine and placed in a galvanized metal flat. Thirty corn plants were grown in each flat. The corn was subirrigated every other day during the beginning of the growth period and every day during the latter part of the growth period. Thirty days after planting the above-

ground parts of the corn plants were harvested, oven-dried, and weighed.

A randomized block experiment with three replications was designed to determine the tolerance of corn to simazine applied either to the soil surface or mixed with the soil. Rates of simazine used were 0, 1, 2, 4, 8, 16, 32, 64, and 128 ppmw. In this test, the soil was surface watered because of the addition of simazine to the soil surface in certain treatments.

Tolerance of six crops to simazine.

This experiment was designed to determine the tolerance of Kindred barley, Marine flax, Caribou rye, Norghum sorghum, Flambeau soybeans, and Selkirk wheat to 0, 0.12, 0.25, 0.50, 1.00, 2.00, 4.00, and 8.00 ppmw of simazine. The simazine was mixed with 3,500 grams of Waukegan silt loam which was placed in a metal flat. Three species, each occupying a single row, were sown per metal flat using sufficient seed to obtain a final population of 20 plants per row. The experimental design was a randomized block with four replications. The occurrence of the crops in the metal flats was completely randomized. The above-ground parts of each crop were harvested 30 days after planting and yield expressed as grams of oven-dry material produced.

Influence of application rates of simazine and water on weed and corn growth.

This experiment was conducted to determine the effect of applied water on the weed control and corn growth obtained following applications of 0, 2, and 4 pounds of simazine per acre. The study was conducted in the field on a Waukegan silt loam soil from May 12 to August 1, 1958. The experimental design was a randomized block with three replications. The plots, 40 by 45 inches, were surrounded by a metal strip, six inches in width, which was driven four inches into the soil. This prevented the applied water from running off the plots. Two days after planting the corn (10 plants per plot), simazine was applied in 80 gallons of water per acre with a small plot sprayer designed by Robinson and Dunham (7). Then, 0, 1, and 2 inches of water was applied with a sprinkling can in ½ inch increments with a one-hour interval between water applications. Rainfall was excluded by means of a plastic cover during the seven-day period immediately following application of the simazine. Quantity of rainfall that fell on these plots after planting was as follows: 0.40 inches in May, 1.73 inches in June, and 3.90 inches in July. On August 1, 1958, the above-ground parts of the corn and weeds were harvested from each plot and the grams of oven-dry corn and weeds produced per plot recorded.

Influence of soil type on simazine phytotoxicity.

This experiment was designed to determine the tolerance of corn, when grown in different soil types, to 0, 4, 16, and 256 ppmw of simazine. The soils used were Waukegan silt loam, Fargo clay, muck, and sand. These soils were selected because of their wide

divergence in organic matter and/or clay content. The corn bioassay procedure, with the simazine mixed in the soil, was followed in this split-plot experiment with four replications.

Influence of soil pH on simazine phytotoxicity.

This experiment was conducted to determine the influence of soil pH on the toxicity of 0, 8, 16, and 32 ppmw of simazine to corn. The buffering capacity of Waukegan silt loam was determined (4) and the pH was adjusted. This was accomplished by adding 47.7, 143.0, or 306.4 grams of calcium oxide to each of three 150-pound lots of Waukegan silt loam which changed the soil pH (after a two-week equilibrium period) from 5.4 to 6.3, 7.2, and 8.5, respectively. The corn bioassay procedure, with the simazine mixed in the soil, was used in this experiment except the corn was harvested 40 days after planting instead of 30. The experimental design was a split-plot with four replications.

Influence of soil temperature of simazine phytotoxicity.

This experiment was conducted to determine the phytotoxicity of 0, 4, 16, and 256 ppmw of simazine at different soil temperatures. The desired quantity of simazine was thoroughly mixed in 14,500 grams of Waukegan silt loam by the use of a 100 gallon "batch mixer". Cylindrical, metal containers were filled with the soil and placed in water baths. Water temperatures of 59, 68, 77, 86, and 95°F. were maintained within ± 1°F. The experiment was conducted in the greenhouse using a split-plot design with two replications. Sufficient seed were planted to obtain a population of 10 corn plants per container. The soil was brought to field capacity at the beginning of the experiment and watered thereafter when the soil surface was dry. The influence of the herbicide was determined by comparing yields of dry material from above-ground parts of corn 30 days after planting.

RESULTS AND DISCUSSION

Quantitative determination of simazine in soil.

Clintland oats was the most sensitive of the three crops used for determining simazine concentrations in Waukegan silt loam

Table 2. Yields of oats grown 30 days in Waukegan silt loam soil treated with various concentrations of simazine.

Simazine ppmw	Yield in grams of dry material per pot
0.00	1.79 [a]
0.03	1.84
0.06	1.89
0.12	1.76
0.25	1.32
0.50	0.78
1.00	0.09
2.00	0.05
4.00	0.04

[a]According to the SNK multiple range test, values connected by the same line do not differ significantly at the 5 percent level.

soil. It was possible to detect significant differences among oat yields due to simazine concentrations of 0, 0.25, 0.50, and 1.00 ppmw (Table 2).

Soybeans were less sensitive than oats in detecting simazine in soil but were especially suitable for measuring simazine at concentrations used in field applications. There was a significant difference among soybean yields due to all simazine application rates except 2 and 4 ppmw (Figure 1). Results show that the temperature, light, and other variations employed in these experiments had no great effect on the soybean bioassay results. The bioassay using soybeans was considered the best of the three used for the following

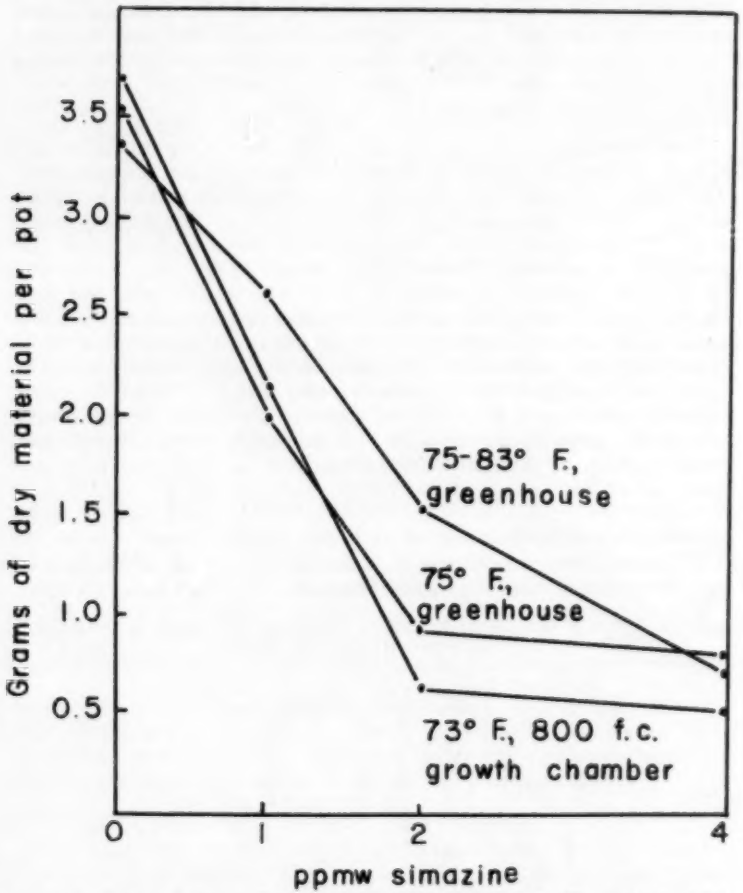

Figure 1. Influence of different climatic conditions on the above-ground yields of soybeans when grown 30 days in simazine treated Waukegan silt loam soil.

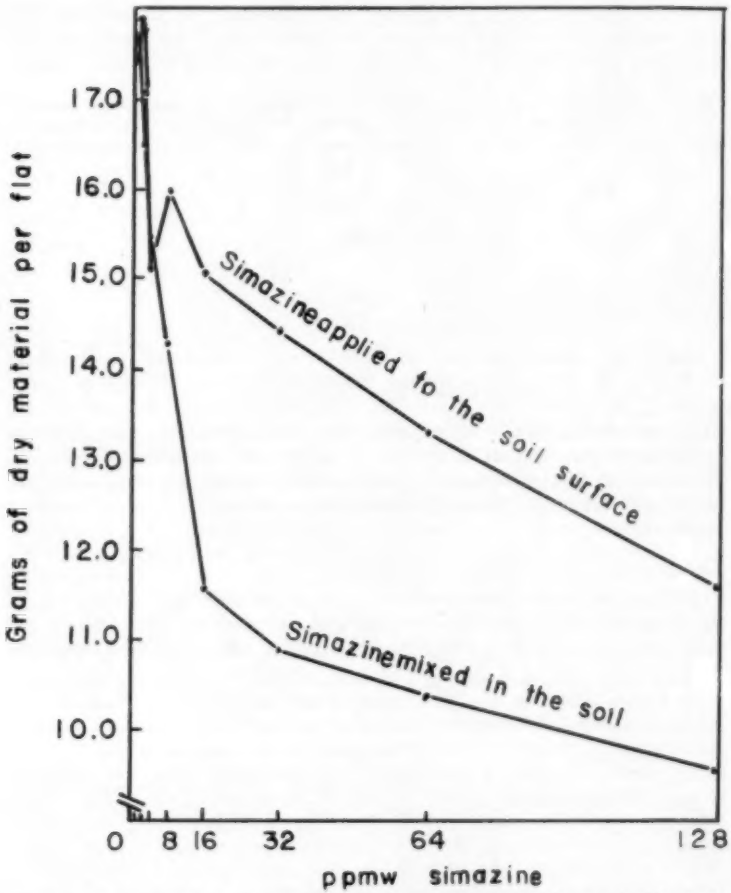

Figure 2. Influence of simazine application methods on the above-ground yields of corn grown 30 days in simazine treated Waukegan silt loam soil.

reasons: (a) it gave the best differentiation between simazine concentrations, (b) dry weight yields followed a linear trend at the lower rates used, (c) it was sensitive in the range of field applications of simazine for selective weed control, (d) it was fairly reproducible under somewhat varied environmental conditions, (e) one can observe injury symptoms on the soybeans at the higher simazine concentrations early in the bioassay, and (f) soybeans are easy to plant and establish.

Mixing simazine in the soil was compared to applying it to the soil surface using 0, 1, 2, 4, 8, 16, 32, 64, and 128 ppmw of simazine

in a test on corn. Corn yield differences showed that many simazine application rates used could not be differentiated by means of the corn bioassay (Table 3). Results indicate that there was little differ-

Table 3. Yields of corn grown 30 days in Waukegan silt loam soil. Averages of plots with simazine mixed into the soil and applied on the surface.

Simazine ppmw	Yields in grams of dry material per flat
0	17.5 [a]
1	17.8 |
2	16.8 |
4	15.3 |
8	15.1 |
16	13.3 |
32	12.7 |
64	11.8 |
128	10.6 |

[a]Values connected by the same line do not differ significantly at the 5 percent level.

ence in corn yields due to simazine concentration regardless of application method at 1, 2 and 4 ppmw of simazine (Figure 2). However, at 8 ppmw and higher concentrations, mixing simazine in the soil caused a greater reduction in corn yield than did surface applications.

Tolerance of six crops to simazine.

This experiment was conducted to determine the tolerance of six crops to eight application rates of simazine. The yield of all crops was significantly reduced by 2 ppmw of simazine (Table 4),

Table 4. Crop yields, expressed as percent of the check, showing the tolerance of six crops grown 30 days in simazine-treated Waukegan silt loam soil.

Simazine ppmw	Crop yields as percent of the check					
	Wheat	Sorghum	Barley	Flax	Soybeans	Rye
0.00	100	100	100	100	100	100
0.12	104	93	67[a]	126	106	114
0.25	93	98	85	98	108	104
0.50	67[a]	121	77	105	87[a]	81[a]
1.00	28	82	26	56[a]	63	47
2.00	11	73[a]	9	11	33	17
4.00	7	28	7	7	21	9
8.00	5	8	8	4	18	8

[a]Smallest simazine concentration causing a significant yield reduction at the 5 percent level.

but the various crops responded differently. The order of tolerance of these crops, on the basis of the simazine concentration inducing a significant yield reduction, was as follows: Norghum sorghum, Marine flax, Flambeau soybeans, Caribou rye, Selkirk wheat, and Kindred barley.

Influence of application rates of simazine and water on weed and corn growth.

The influence of water applied after herbicide application plus seasonal rainfall (6.03 inches) on the response of corn and weeds

Table 5. Yields of weeds and corn as a measure of the influence of applied water on simazine phytotoxicity in the field.

Plants	Inches of applied water	Grams dry weight per plot treated with simazine at, lb/A		
		0	2	4
Weeds	0	280	80	20
	1	360	40	10
	2	330	20	4
Corn	0	700	860	830
	1	630	820	810
	2	520	820	800
Total	0	980	940	850
	1	990	860	820
	2	850	840	804

to simazine was studied under field conditions (Table 5). Application rates of 2 and 4 pounds of simazine per acre in the field significantly increased corn and decreased weed dry weight yields of above-ground parts as compared to plots receiving no simazine. It was found that adding 0, 1, and 2 inches of water after applying the simazine significantly influenced the results obtained. If no simazine was applied, the dry weight yields of weeds increased when water was added. However, if either 2 or 4 pounds of simazine per acre was applied, the yield of weeds decreased when one inch of water was applied and decreased still further when two inches of water was applied. Derscheid (3) noted that quicker weed kill was induced by simazine during 1957 than during 1958 in the field. He attributed this to the beneficial leaching of simazine by 5.93 inches of rain that fell within two weeks after the simazine application in 1957 in contrast to negligible leaching of simazine by 0.06 inches of rainfall during the comparable two-week period in 1958. Davis et al. (2) demonstrated that when radioactive simazine was applied to the soil surface, a greater amount of radioactivity was found in cotton plants growing in this soil if surface watering was practiced rather than subirrigation. These data indicate that more phytotoxicity will be realized from a given simazine application if the simazine is leached into the soil with water. Presumably, this is because the simazine is carried into the root zone where it is more likely to be absorbed by the plants. However, if this leaching is excessive (Table 5) or if the simazine is mixed in the soil (Figure 2) the selective herbicidal action of simazine to corn is decreased. Nevertheless, the tolerance of corn and susceptibilty of annual weeds to simazine demonstrated that there is a considerable margin of safety for the selective control of annual weeds in corn using this herbicide.

Influence of soil type on simazine phytotoxicity.

An experiment was conducted to determine the influence of Waukegan silt loam, Fargo clay, muck, and sand on the toxicity of 0, 4, 16, and 256 ppmw of simazine to corn. The great difference in corn yields on the four soils reflects the considerable variability

in soil fertility, with a six-fold greater corn yield on muck than on sand when no simazine was applied. The different soils also had a significant effect on the response of corn to simazine. The 4 ppmw of simazine in Fargo clay and 4 and 16 ppmw of simazine in muck cause little relative reduction in dry weight yield of the above-ground parts of corn (Figure 3). Sheets (11) found that phytotoxicity of simazine is less in soil than solution cultures. He showed that a considerable amount of simazine applied to soil was fixed in a form unavailable to plants. Oats grown in solution cultures took 0.028 ppmw of simazine compared to 0.43 ppmw in Yolo clay loam to reduce the fresh weight 50 per cent. To reduce the fresh weight

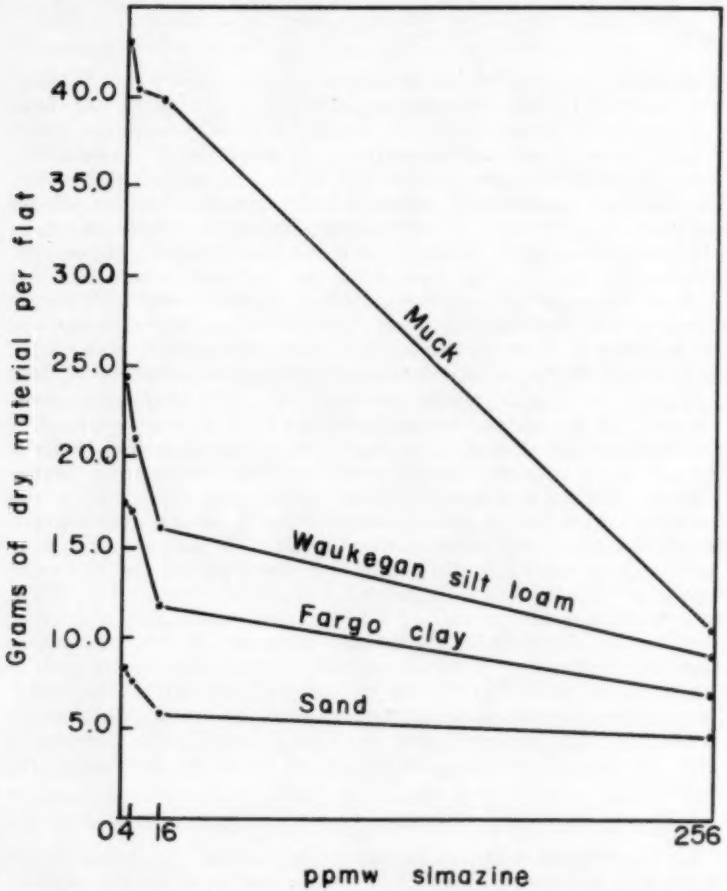

Figure 3. Influence of soil type on the above-ground yields of corn grown 30 days in simazine treated soil.

of soybeans 50 per cent, it took 0.069 ppmw of simazine in solution cultures and 1.64 ppmw in Sacramento clay. These data indicate that some simazine is absorbed by the colloidal fraction of soil in a form unavailable to the plant. Therefore, one would have to use higher application rates of simazine on a clay as compared to a sandy soil for equivalent weed control.

Influence of soil pH on simazine phytotoxicity.

The influence of soil pH on the toxic action of simazine to corn was studied using Waukegan silt loam with its pH adjusted from 5.4 to 6.3, 7.2, and 8.5 with calcium oxide. There was a significant decline in corn yield as the simazine application rate and the soil pH level were increased (Table 6). A highly significant pH × simazine rates interaction showed that soil pH had an effect on the toxic action of simazine to corn. However, further experimentation is needed to more fully elucidate this effect.

Table 6. Corn yields indicating the toxicity of simazine to corn grown 30 days in Waukegan silt loam at different soil pH levels (adjusted with calcium oxide).

Simazine ppmw	Soil pH			
	5.4	6.3	7.2	8.5
	Corn yields in grams per flat			
0	15.5	15.8	11.3	9.9
8	13.5	14.3	8.3	7.5
16	10.4	9.4	7.4	6.1
32	8.4	7.6	6.6	5.4
	Corn yields as percentage of the check			
0	100	100	100	100
8	87	90	74	75
16	68	60	65	62
32	54	48	58	55

Influence of soil temperature on simazine phytotoxicity.

The influence of soil temperature on simazine toxicity to corn was determined using soil temperatures of 59, 68, 77, 86, and 95°F. and 0, 4, 16, and 256 ppmw of simazine. Without simazine, dry weight yield of above-ground parts of corn increased 10 fold when the soil temperature was increased from 59 to 86°F. and decreased substantially at 95°F. (Table 7). When simazine was present at 16 and 256 ppmw, higher temperatures caused only a small increase in corn yield as compared to the corn yield from 0 and 4 ppmw of simazine. SNK multiple range tests at the 5 per cent level disclosed a significant difference in corn yield at all soil temperatures, and corn yields were reduced significantly by 4, 16, and 256 ppmw of simazine. A highly significant simazine rates × temperatures interaction showed that temperature had an influence on the response of corn to simazine. Increasing soil temperature from 59 to 86°F. caused increasing simazine toxicity to corn. Schneider (10) cites observations where plants growing under ideal conditions were killed more rapidly by simazine than plants growing under

Table 7. Corn yields indicating the toxicity of simazine to corn grown 30 days in Waukegan silt loam at different soil temperatures.

Simazine ppmw	Soil temperature in degrees F.				
	59°	68°	77°	86°	95°
	Corn yields in grams per container				
0	2.5	8.4	20.9	30.6	23.2
4	1.6	5.5	11.3	13.5	15.6
16	1.2	2.5	3.4	4.3	3.3
256	1.2	1.6	2.1	2.1	2.0
	Corn yields as percentage of the check				
0	100	100	100	100	100
4	66	65	54	44	67
16	50	30	16	14	14
256	48	20	10	7	9

low temperatures. Increased plant response at higher temperatures may be due to greater simazine uptake as metabolic activity is accelerated by the higher temperatures. Also, the experiment on soil type and work by Sheets (11) provide evidence that simazine may be absorbed to soil colloids. Since absorption is an exothermic reaction, there would be a reduction in the amount of absorbed simazine at higher soil temperatures. This could also be a factor in causing the increased simazine toxicity to the corn at higher temperatures.

SUMMARY

Environmental factors influencing simazine phytotoxicity and the quantitative determination of simazine in soil were studied.

Clintland oats, Flambeau soybeans, and single cross A502 × A556 corn were the three bioassay crops used to quantitatively determine the amount of simazine in Waukegan silt loam. The oats, soybeans, and corn were sensitive in the ranges of 0.25 to 1, 0.5 to 4, and 4 to 256 ppmw of simazine, respectively.

There is a wide margin of safety for the selective control of annual weeds in corn with simazine. Application rates of 2 and 4 pounds of simazine per acre significantly increased corn and decreased weed dry weight yields of above-ground parts grown in Waukegan silt loam soil in a field experiment.

The response of seven field crops to simazine, based on the simazine concentration inducing a significant yield reduction, are listed from most tolerant to most susceptible as follows: single cross A502 × A556 corn, Norghum sorghum, Marine flax, Flambeau soybeans, Caribou rye, Selkirk wheat, and Kindred barley.

Soils high in organic matter and/or clay content caused reduced simazine phytotoxicity as compared to soils low in these components.

Increasing soil temperature, within limits, caused increased simazine toxicity to corn.

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News and Notes

Joe L. Key joined the staff of the Department of Botany at University of California, Davis, on September 1, 1960. He obtained Ph.D. degree at Illinois. He was on a NSF grant during the spring and summer.

Merrill Wilcox was appointed Assistant Agronomist at the Florida Agricultural Experiment Station, Gainesville, on June 1, 1960, to devote full time to weed control research. He expects to receive the Ph.D. degree from North Carolina State College in the near future.

G. F. Warren has been in Europe for a sabbatical. He traveled in several countries on the Continent, and is spending 3 or 4 months at Oxford. He will return about February 1.

K. P. Buchholtz gave an invitation paper at the Fifth British Weed Control Conference at Brighton November 8, 1960. He visited research stations in Holland, Belgium, England, Scotland, and Wales before the meeting.

Earl G. Helgeson is also in Europe on a sabbatical, spending considerable time in the Scandinavian countries and attending the British Weed Control Conference. He left September 1, 1960, and will return about April 1.

E. G. Rodgers was elected International Vice-President of Gamma Sigma Delta at its biennial conclave at Raleigh, North Carolina, in June, 1960.

H. R. Keyser received the Ph.D. degree from the University of Wisconsin, and is now employed in industrial herbicide work by the National Aluminate Company of Chicago.

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for
April, May, June, 1960

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Prepared By

UNITED STATES DEPARTMENT OF AGRICULTURE

Agricultural Research Service

Crops Research Division

Weed Investigations Section

This bibliography of current literature on weeds and their control is issued as a service to those engaged in weed research in the United States and other countries. In issuing this bibliography the Crops Research Division, Agricultural Research Service, U.S.D.A. does not assume responsibility for the subject matter cited.

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IX. Legal Aspects

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Suggestions for Contributors to WEEDS

Manuscripts dealing with all aspects of weed control, regulatory, educational and research, are accepted for publication in WEEDS. Manuscripts should have more than purely local interest. The material described should be more conclusive than progress reports. Articles must be original material previously unpublished elsewhere. Prior publication in brief abstract form is permitted. After review, each manuscript will be accepted for publication upon recommendation of the Editorial Board. The author has the opportunity to make revisions after the review is completed and before publication. Refer to a recent issue of WEEDS to determine details of style to be used.

Manuscripts. Two copies, one on bond paper, should be furnished for each manuscript. The entire text, including the title, footnotes and literature cited, should be double spaced. An additional copy of the manuscript should be retained by the author to ensure against loss.

Use as short a title as practical. Following the title give the authors name(s). It is desirable to divide the manuscript into sections with headings such as Methods and Materials, Results, Discussion, Summary, and Literature Cited. "Results" and "Discussion" may often be profitably combined in a single section, and no rigid requirement of the above divisions is implied. Avoid underscoring headings, words or phrases unless you wish them to be printed in italics. Do not use solid capitals for titles.

Measurements such as time, weight and degrees should be in arabic numerals regardless of the number of digits in the number. Where the figure is not one of measurement, figures below 10 should be spelled out except when one figure in a series has two digits in which case all should be in arabic.

The full chemical name or description of all chemicals mentioned should be given the first time used. Nomenclature, abbreviations and definitions should follow those presented in the Terminology Committee Report, WSA, published in WEEDS 8:487–495, July, 1960.

Footnotes. Use footnotes sparingly for items that cannot be included conveniently in the text. The place where the study was done and the address of the author(s) should be given as footnotes. Number footnotes to the text consecutively throughout the manuscript with superscript arabic numerals. Designate footnotes to the tables with superscript lower case letters.

Figures. Experimental data may be presented in graphic or tabular form. However, figures should not be used if they merely illustrate material presented in the text or in tables. Prepare illustrations with approximately the same proportions as a printed page, $4^3/_4$ x 7 inches, or some fraction of a page. Photographs should be clear glossy prints and should be trimmed of unessential portions. Do not use clips on photographs in any way.

Graphs and drawings should be inked with heavy black lines to ensure clarity after reduction in size. Hand lettering should be large and made with a lettering guide. Typing is not acceptable. Place the author's name and figure number on the back of each one submitted. Type the legends for all figures on one sheet separate from the figures, and double spaced. Figures should be numbered consecutively in arabic numerals.

Tables. Type each table on a separate sheet. Tables should be numbered consecutively in arabic numerals in order of reference in the text. In tables, the caption, column headings and side headings should be in lower case with only the first word and proper nouns capitalized.

Citations. Citations are numbered alphabetically by senior author and the number of the reference is used in the text. Citations should include names of all authors, complete title, volume number, inclusive pages, publication and year. Theses and letters, or any other communication not readily available in libraries, should appear as footnotes.